FINAL
COMPLETION REPORT
CHARACTERIZATION WELL R-34
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO
PROJECT NO. 37151

Prepared for:

The United States Department of Energy and the
National Nuclear Security Administration through the
United States Army Corps of Engineers
Sacramento District

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Appendices

Figures

Tables

LIST OF ACRONYMS AND ABBREVIATIONS

amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
°C	degrees Celsius
CD	compact disc
CQMP	Contractor's Quality Management Plan
DOE	U.S. Department of Energy
DTH	down-the-hole
DTHH	down-the-hole hammer
DTW	depth to water
DVD	digital video disc
EES	Earth and Environmental Sciences
ELAN	Elemental Analysis
FMI	formation microimager
ft	foot/feet
g	grams
g/cc	grams per cubic centimeter
gal	gallon
gpm	gallons per minute
GPS	Global Positioning System
hp	horsepower
HSA	hollow-stem auger
ID	inner diameter
in	inch
KA	Kleinfelder, Inc.
KBr	potassium bromide
LANL	Los Alamos National Laboratory
mS/cm	milliSiemens per centimeter
NAD	North American Datum
NGVD	National Geodetic Vertical Datum
NM	not measured
NMED	New Mexico Environment Department
NOI	Notice of Intent
NTU	nephelometric turbidity unit
OD	outer diameter
PMP	Project Management Plan
psi	pounds per square inch
RCT	Radiation Control Technician
SAP	Sampling and Analysis Plan
SMO	Sample Management Office
SOP	Standard Operating Procedure
SSHASP	Site-Specific Health and Safety Plan
TA	Technical Area
TD	total depth
TDS	total dissolved solids

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

USACE	U.S. Army Corps of Engineers
WDC	WDC Exploration & Wells

ABSTRACT

Characterization Well R-34 was installed on San Ildefonso Pueblo property adjacent to Los Alamos National Laboratory (LANL) under the Groundwater Protection Program in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (January 2004, LA-UR-04-0165). The U.S. Department of Energy (DOE) contracted and directed the installation of R-34 with technical assistance from LANL. R-34 is located in Cedro Canyon approximately 1,500 feet south of Mortandad Canyon on San Ildefonso Pueblo property. The well is intended to provide hydrogeologic and water quality data regarding regional groundwater downgradient of potential contaminant sources in Mortandad Canyon. The data will be used in conjunction with similar data from other wells in the area to improve the conceptual model of the geology, hydrogeology, and hydrochemistry and to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone and the regional aquifer.

At R-34, the majority of the fieldwork was conducted from June 28 through September 17, 2004. The borehole at R-34 was drilled to a depth of 1,065 feet using normal circulation air and fluid-assisted air-rotary methods. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis. The stratigraphy encountered during borehole drilling included, in descending order, alluvium, ash-flow tuffs of the Tshirege and Otowi Members of the Bandelier Tuff, the Guaje Pumice Bed of the Otowi Member, Cerros del Rio basalt, and the Puye Formation.

The well at R-34 was installed in the regional aquifer with a screen interval from 883.7 to 906.6 feet below ground surface. One groundwater screening sample was collected during drilling. A separate groundwater sample was collected near the end of well development. The groundwater samples were submitted to LANL for analysis. Additionally, a constant-rate pumping test was conducted to determine aquifer properties.

Overall, the well drilling and construction process was more difficult than anticipated. The primary difficulty was borehole wall instability caused by a thick section of scoriaceous basalt. These scoriaceous basaltic sections of the Cerros del Rio basalt were not expected based on prior information and had a tendency to slough, resulting in the formation of bridges that required additional borehole reaming. The borehole was also drilled deeper than originally planned. This was done to ensure that the well would penetrate a sufficient depth into the regional zone of saturation.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, aquifer testing, and related activities conducted from June 28 to September 17, 2004 for Characterization Well R-34 (R-34). R-34 was drilled on San Ildefonso Pueblo adjacent to Los Alamos National Laboratory (LANL or the Laboratory). R-34 was drilled and installed as part of LANL's Groundwater Protection Program, and the work was funded and directed by the U.S. Department of Energy (DOE). Kleinfelder, Inc. (KA), under contract to the U.S. Army Corps of Engineers (USACE), was responsible for executing the drilling, installation, testing, and sampling activities.

The information presented in this report was compiled from field reports and activity summaries generated by KA, LANL, and subcontractor personnel. Original records, including field reports, field logs, survey records, and so on, are on file in KA's Albuquerque office. Results of these activities are discussed briefly and shown in tables and figures contained in this report. Detailed analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

R-34 is located on San Ildefonso Pueblo land approximately 1,500 feet (ft) south of Mortandad Canyon in Cedro Canyon. It provides a monitoring point for the regional aquifer approximately midway between wells R-13 and R-22 (Figure 1.0-1). Data from R-34 will also help determine the nature and define the extent of potential contamination in the regional aquifer in the vicinity of the eastern (lower) portion of Mortandad Canyon

The potential contaminants being investigated in the regional aquifer in this area are radionuclides, metals, nitrate, perchlorate, chloride, sulfate, fluoride and excessive Total Dissolved Solids (TDS), as indicated in the LANL-prepared Sampling and Analysis Plan (SAP) (LANL 2003, LA-UR-03-8324). Data from R-34 will be evaluated in conjunction with data from other area wells to form the technical basis for the design of a groundwater monitoring system, if needed. Water quality, geochemical, aquifer, and geologic information obtained from R-34 will augment knowledge of regional subsurface characteristics and the distribution of contaminants in the regional aquifer downgradient of potential release sites.

2.0 PRELIMINARY ACTIVITIES

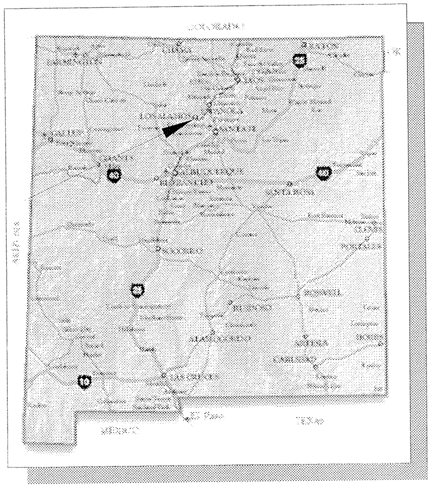
Preliminary activities included administrative planning and site preparation.

2.1 Administrative Preparation

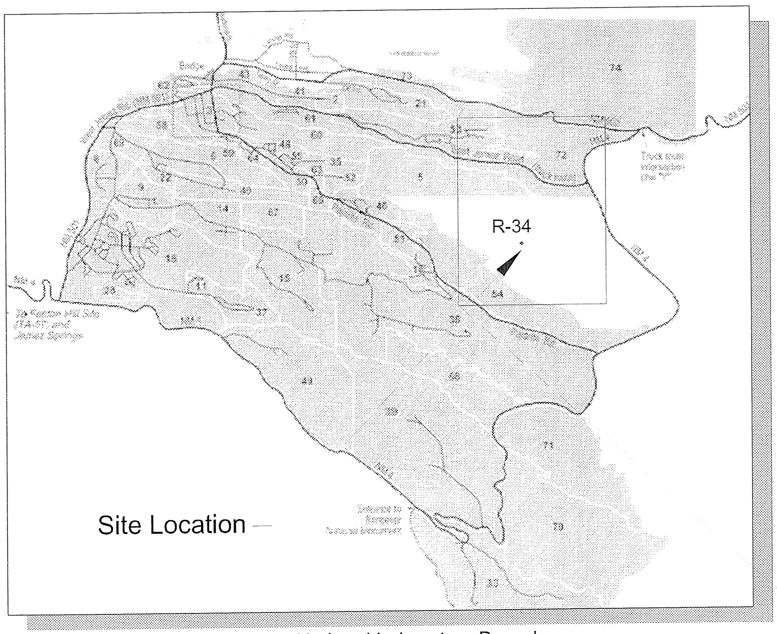
KA received contractual authorization to start administrative preparation tasks in the form of a notice to proceed on June 24, 2004. As part of administrative preparation, KA had previously developed a Project Management Plan (KA 2003a), a Contractor's Quality Management Plan (KA 2003b), a Site-Specific Health and Safety Plan (KA 2003c), and a Drilling Plan (KA 2003d) for the work at R-34. DOE obtained a permit (RPM-FY04-023) from the San Ildefonso Pueblo prior to beginning fieldwork.

2.2 Site Preparation

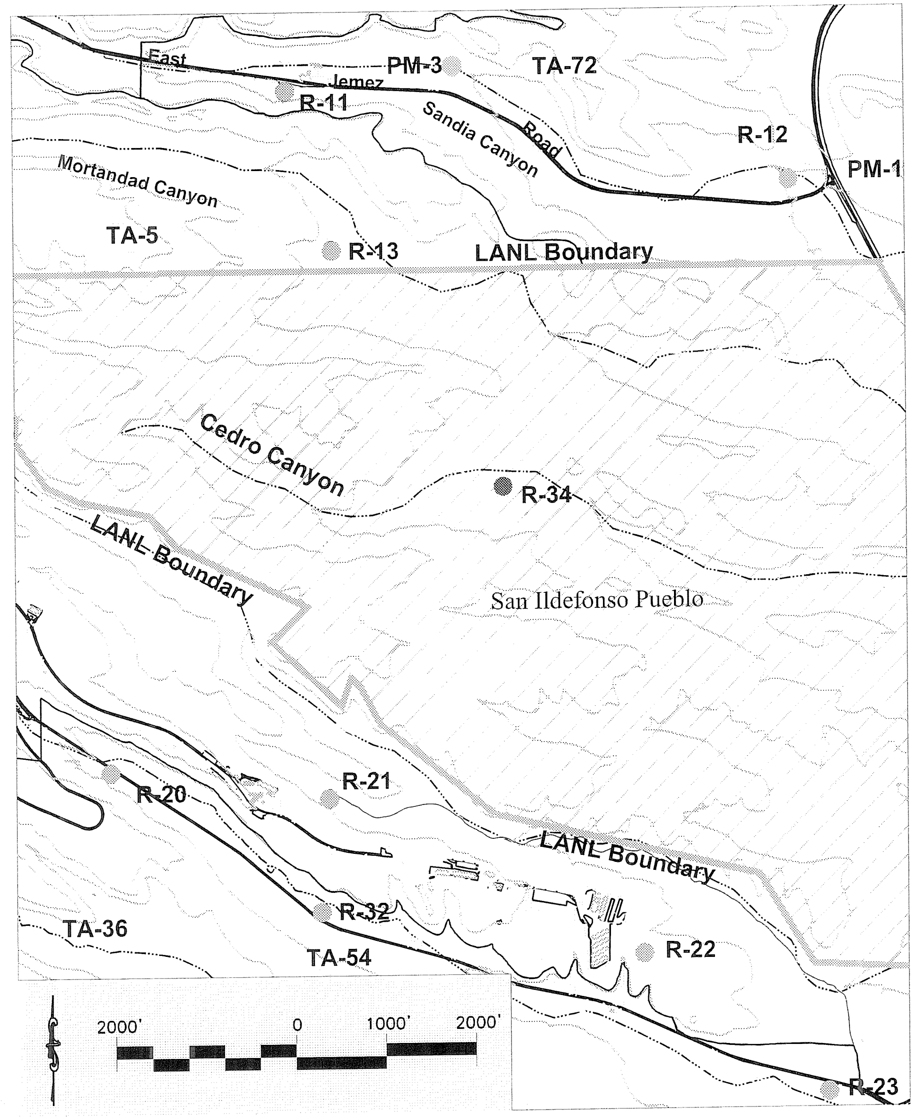
EnviroWorks, Inc. (EnviroWorks) was subcontracted by KA to conduct site preparation for R-34. Activities included access road improvements, site clearing, construction of the drill pad, Los Alamos



Site Location



Los Alamos National Laboratory Boundary



R-34 Characterization Well

Municipal Water Supply Well

Existing R Characterization Wells

KLEINFELDER

Drawn By: C. Landon

Project No.: 37151

Date: November 2004

Filename: Figure 1.0-1.dwg

SITE LOCATION MAP

Characterization Well R-34

San Ildefonso Pueblo

Los Alamos National Laboratory

Los Alamos, New Mexico

FIGURE

1.0-1

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and construction of a lined borehole-cuttings containment area. Site preparation began on June 28, 2004, and the majority of work was completed by July 6, 2004. Radiation Control Technicians (RCTs) from the LANL HSR-1 group and representatives of San Ildefonso Pueblo were present to screen the site during preparation activities.

After vegetation was cleared from the drill site, a drilling pad was prepared by grading an area approximately 150 ft by 150 ft with a front-end loader. Two layers of base-course gravel were distributed over the drill pad, equipment storage area, and access road, as necessary. To store drilling fluids and borehole cuttings, a 40-ft wide by 60-ft long by 7-ft deep containment area was excavated along the eastern pad boundary. Safety barriers and signs were installed around the borehole-cuttings containment area and at the pad entrance.

Office and supply trailers, generators, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment. Potable water was trucked to the site from a hydrant next to Building 52-117 on the mesa south of Mortandad Canyon. KSL personnel installed a backflow prevention system at the hydrant.

3.0 DRILLING ACTIVITIES

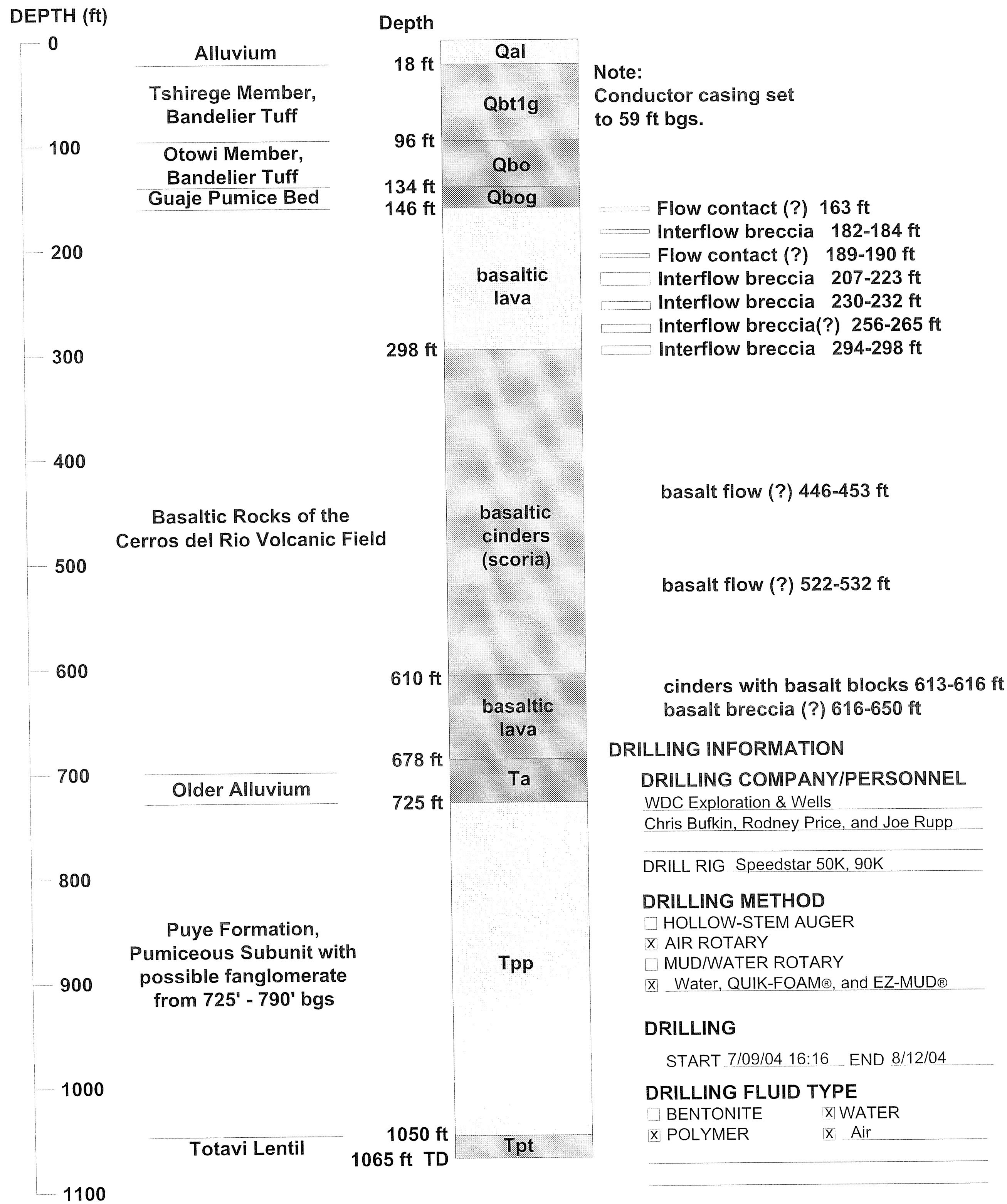
R-34 was drilled between July 9 and August 12, 2004. The objectives of the drilling were to collect cuttings of intersected geologic formations, collect groundwater samples from significant perched water (if encountered) and the regional aquifer, provide a borehole for geophysical logging, and install a single-screen monitoring well in the regional aquifer. The planned total depth (TD) of the borehole was approximately 1,015 ft below ground surface (bgs), or about 100 ft below the estimated depth to the top of the regional water table. The borehole was actually drilled to a TD of 1,065 ft bgs to achieve adequate well screen depth below the regional water table. Drilling activities were performed generally in one 12-hour shift per day, 7 days per week, by the drill crew and two site geologists.

Figure 3.0-1 presents a borehole summary data sheet and graphically depicts the geology encountered during drilling activities. A chronology of drilling and other project activities, presented in chart form, is shown as Table 3.0-1. Specific details are discussed below.

WDC Exploration & Wells (WDC) performed the drilling for R-34. A GEFCO Speedstar 90K was used for the first 2 weeks of drilling, but it was replaced with a Speedstar 50K due to mechanical difficulties. The Speedstar 90K was repaired and used for the final week of drilling. Both rigs were equipped with conventional circulation drilling rods, tricone bits, down-the-hole hammer (DTHH) bits, and support equipment.

R-34 was drilled using air-rotary and fluid-assisted air-rotary drilling techniques. Drilling fluids were used as needed to improve borehole stability, minimize fluid loss, and facilitate cuttings removal from the borehole. Drilling fluids consisted of a mixture of municipal water with QUIK-FOAM® surfactant and EZ-MUD® polymer. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total drilling fluids recovered, is presented in Table 3.0-2. Depth-to-water (DTW) measurements were initially taken at the beginning and end of every shift to check for the presence of water. However, this practice was largely abandoned as the borehole depth increased due to the presence of scoriaceous basalt that caused unstable downhole conditions.

R-34



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL

WDC Exploration & Wells
Chris Bufkin, Rodney Price, and Joe Rupp

DRILL RIG Speedstar 50K, 90K

DRILLING METHOD

- ☐ HOLLOW-STEM AUGER
- ☒ AIR ROTARY
- ☐ MUD/WATER ROTARY
- ☒ Water, QUIK-FOAM®, and EZ-MUD®

DRILLING

START 7/09/04 16:16 END 8/12/04

DRILLING FLUID TYPE

- ☐ BENTONITE
- ☒ WATER
- ☒ POLYMER
- ☒ Air

Note: Locations of geologic contacts are preliminary and subject to change.

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Project No.: 37151

Date: November 2004
Filename: Fig 3.0-1.dwg

BOREHOLE SUMMARY DATA SHEET
Characterization Well R-34
San Ildefonso Pueblo
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE 3.0-1

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Table 3.0-1. Chronology of Operations for Well R-34

TASK	Jun-04		Jul-04				Aug-04				Sep-04			
SITE PREPARATION ACTIVITIES		6/28 --7/6												
BOREHOLE DRILLING/SAMPLING				7/9 -- 8/12										
Mobilization				7/6-7/9										
Air-Rotary					7/9 - 7/29									
Fluid Assisted Air-Rotary						7/30,31		8/7 -- 8/12						
Groundwater Screening Sampling							8/5							
BOREHOLE GEOPHYSICS														
Schlumberger Logging								8/9,10						
LANL Video							8/4	8/10						
WELL DESIGN AND CONSTRUCTION									8/13 - 8/20					
WELL DEVELOPMENT										8/27 -- 9/2				
GROUNDWATER WELL SAMPLING											9/2			
HYDROLOGIC TESTING												9/11 -- 13		
SITE RESTORATION													Began Sep-04	

NOTE: NMED discharge approval was received in an email dated November 10, 2004 (Appendix F).

Table 3.0-2
Introduced and Recovered Fluids

Material		Amount (Gallons)
Introduced	QUIK-FOAM®	446
	EZ-MUD®	37
	Potable Water	36,204
	Defoaming Agent	4
	Total Introduced	36,691
Recovered	Total Recovered Fluids[a]	66,972

[a] "Total Recovered Fluids" represents the estimated fluid volume recovered during drilling, well development and hydrologic testing.

Beginning on July 6, 2004, WDC mobilized drilling equipment and supplies to the R-34 site. On July 9, the drillers began drilling operations by installing 13⅝-inch (in) outer diameter (OD) drill casing from the ground surface to a depth of 57 ft bgs. The casing appeared to have encountered the Tshirege Member of the Bandelier Tuff at a depth of about 18 ft bgs. The inside of the casing was drilled out and the borehole carried to a depth of about 60 ft bgs using a 12¼-in tricone bit.

On July 10, 2004, the casing was driven an additional 2 feet to a total depth of 59 ft bgs. Drilling with a 12¼-in OD DTHH bit progressed to a depth of about 138 ft bgs, at which point the driller reported that the DTHH bit felt as if it had fallen a couple of feet, indicating a zone of lower resistance. Drilling continued but with limited air and cuttings return. Circulation improved and drilling continued to a depth of 152 ft bgs where drilling resistance increased noticeably due to entering the Cerros del Rio basalt. Drilling continued to a total depth of 226 ft bgs and was variably difficult due to poor circulation and cuttings removal. Potassium bromide (KBr) was added to the drilling fluid as a tracer at 200 ft bgs to aid in identifying perched water; details of the KBr tracer test methodology are presented in Section 6.2.

On July 11, 2004, the drill pipe was tripped out of the hole from 226 ft bgs. No water was detected in the borehole. Drilling resumed with the DTHH to 260 ft bgs. Drilling ceased for the shift at this depth due to a crack in the tophead quill. The drill string was tripped out and DTW measurements indicated approximately 0.2 ft of liquid, likely drilling fluids, was in the hole. However, no sample could be obtained because of the small volume of liquid.

No borehole drilling activities were performed from July 12 to 19, 2004, due to training and accrued days off.

On July 20, 2004, drilling resumed with the 12¼-in OD DTHH bit, and the borehole was advanced to a depth of 486 ft bgs using a mixture of air-rotary and foam-assisted air-rotary techniques. During this interval, a large washout developed between 300 and 325 ft bgs. Intervals of minor resistance to essentially no resistance were encountered from 325 to 345 ft bgs. From 345 to 486 ft bgs, the drilling continued to exhibit variable and, at times, poor circulation and cuttings returns. The driller tripped out a portion of the drill tools but left approximately 205 ft of drill stem in the hole. The remaining tools were tripped out the following morning, July 21, and an attempt was made to measure the DTW; however, no groundwater was present in the borehole. On this day, drilling continued to a total depth of 563 ft bgs, again using a mixture of air only and air plus foam with similar performance characteristics as the previous day. Difficulties were again encountered during tripping out and a portion of the drill string was left in the borehole at the end of the shift. A new KBr system was deployed that could provide automatic injection of the KBr to the drilling fluids as well as real-time determination of KBr values using automated probes.

On the morning of July 22, 2004, the crew continued to trip rod out of the borehole to measure DTW, and the DTHH bit was replaced with a 12¼-in tricone bit to improve circulation. A positive reading was measured for the DTW, but personnel present at the site concluded that the reading was from drilling fluids that had accumulated at the bottom of the borehole and not a perched or regional water table. While tripping the tools back in, the drillers encountered difficulty with the drill rod sticking between 163 and 183 ft bgs. This was corrected by reaming with the tricone bit as it was tripped into the borehole. Drilling continued to a new depth of 630 ft bgs. The driller reported an increase in the drilling resistance due to the formation at approximately 630 ft bgs. DOE permitted the drillers to trip out only 100 feet of drill rod and leave the balance in the borehole overnight.

Drilling activities on July 23 and 24, 2004 produced no advance of the borehole, and the Speedstar 90K encountered mechanical problems with the ram. The drilling crew determined that the mechanical problem could not be repaired on site and that the remaining rods in the borehole also could not be pulled. A replacement drill rig was ordered, and the Speedstar 90K was moved offsite.

On the morning of July 25, 2004, a downhole video survey was performed to evaluate the condition of the borehole. The video log showed borehole washouts and a bridge in the borehole at a depth of about 424 ft bgs. On July 26, the drillers decided to fill the bottom portion of the borehole with sand between the bridge and the bottom of the void encountered previously, followed by a plug of concrete within the void area. The drillers tagged the bridge depth at 417 ft bgs. Sand was placed from the bridge to approximately 375 ft bgs. This was followed by placement of approximately 36 cubic yards of concrete to a tag depth of 305 ft bgs. Additionally, two supersacks of hydrated bentonite chips were used to fill the remaining void space up to about 302 ft bgs.

On July 27, 2004, a replacement drill rig, a Speedstar 50K, was mobilized to the site. A measurement of the depth to the top of the plug was made, and it was found that the plug had swelled upward approximately 1 foot, reducing the total depth to the top of the plug to 301 ft bgs. Drilling commenced from 301 to 480 ft bgs. Over the course of several days (July 27 to 29), the drillers reached a total depth of 633 ft bgs using a 12¼-in tricone bit.

From July 30 to 31, 2004, drilling progressed from 633 ft bgs to the actual TD of the borehole at 1,065 ft bgs. QUIK-FOAM®, EZ MUD®, and water were used to complete this portion of the work. Within this period, poor circulation resulted in few cuttings being returned to the surface. The lithologic log (Appendix D) shows significant intervals of no returns, principally in the Cerros del Rio cinder zone and below the Older Alluvium. During drilling, groundwater was first recognized at a depth of about 925 ft bgs, a depth based on the increased volume of liquid discharged from the borehole. Between August 1 and 2, the tools were tripped out and a 12¼-in button tricone reaming tool was reinserted into the borehole. The driller estimated, based on a rise in drilling fluid pressure, that the water table was at 900 to 910 ft bgs. Numerous attempts were made to accurately measure the DTW, but interference from excessive foam remaining in the borehole prevented accurate measurements.

On August 3, 2004, Schlumberger mobilized to the drill site. Schlumberger personnel attempted to collect geophysical readings from the borehole. However, as the probe was lowered to a depth of about 692 ft bgs, a bridge was encountered. It was determined that the borehole had squeezed closed due to swelling clay.

The LANL video logging equipment was mobilized to the borehole on August 4, 2004, to evaluate the cause of the difficulties associated with the geophysical logging. Video logging was completed to a depth of about 640 ft bgs, at which point foam and liquid were encountered, creating very poor image quality, and the video logging operation was suspended. During initial lowering of the video camera, it was discovered that there were two boreholes beginning at a depth of about 388 ft bgs. After the camera was withdrawn from the first borehole, it was then lowered down into the second borehole. The camera was lowered to a depth of 465 ft bgs, at which point the bottom was encountered. No foam or liquid was encountered in this second borehole. An aqueous sample was collected from the liquid accumulating on the bridge in the deeper foam/liquid-filled hole to evaluate the constituents of the drilling fluids.

An aqueous sample (Sample ID: GW34-04-53519) was collected from the borehole on August 5, 2004, at 1:42 p.m. from a depth between 641.4 and 664 ft bgs. A second water sample (Sample ID: GW34-04-53520) was collected from the onsite water storage tank on August 6 at 10:20 a.m. The source for replenishing the onsite water storage tank is the fire hydrant located across from Building 52-117. Both samples were submitted to the Sample Management Office (SMO).

On August 7, 2004, WDC mobilized the Speedstar 90K drill rig back to the site, initiated and completed rig setup, and began to trip in casing for borehole reaming. The DTW of the fluids accumulated above the bridge was measured at approximately 641 ft bgs. WDC continued to trip in an 8½-in tricone bit and advance drill casing on August 8, but encountered blockage at about 700 ft bgs due to swelling clay. The 9⅝-in diameter casing was advanced to a total depth of 739 ft bgs, and the borehole was reamed to about 800 ft bgs.

On August 9, 2004, WDC continued to ream the borehole to the final TD of 1,065 ft bgs and tested the borehole stability by tripping out 100 feet of drill stem. The trip out was clean, and WDC decided to trip out the remaining tools in preparation for geophysical logging by Schlumberger.

Schlumberger began preparations for geophysical logging on August 9, 2004, and completed the work on August 10, 2004. Between August 11 and 12, 2004, WDC reentered the borehole to ream out slough and bridging that had occurred. Late on August 12, 2004, WDC began final trip out in preparation for installation of the well.

Following completion of the borehole, a well was installed and completed in the regional aquifer with a screened interval from 883.7 to 906.6 ft bgs. Well design and construction are discussed in Section 7.0.

4.0 SAMPLING AND ANALYSIS OF BOREHOLE DRILL CUTTINGS AND GROUNDWATER

During drilling at R-34, cuttings and water samples were collected according to the LANL-prepared SAP. Drill cuttings and water samples were submitted to the LANL SMO for analysis.

Cuttings collected from the R-34 borehole will be analyzed for mineralogic, petrographic, and geochemical properties. Water samples were analyzed for organic, inorganic, and radiochemical compounds and geochemical properties.

4.1 Sampling of Borehole Drill Cuttings

As drilling conditions permitted, sufficient quantities of cuttings were collected at approximately 5-ft intervals from the borehole waste discharge line. Portions of the cuttings were sieved (using >#10 and >#35 mesh, or >#35 and >#60 for finer-grained samples) and placed in chip-trays along with unsieved cuttings. The cuttings were examined to determine lithologic characteristics and used to prepare the lithologic logs. An additional aliquot of the >#10 fraction of cuttings was prepared for all intervals where sufficient returns were available. The sieved fractions were placed in labeled plastic bags and submitted to LANL. The remaining cuttings were sealed in Ziploc® bags, labeled and archived in core boxes. Up to seven samples may be removed by LANL for mineralogic, petrographic, and geochemical analyses. No cuttings samples were submitted for contaminant characterization. However, all cuttings were screened by the RCTs prior to removal from the site.

Sample analytical results will be included in a future LANL investigation report for Mortandad Canyon.

4.2 Water Sampling

One aqueous sample was collected from the borehole on August 5, 2004, at a depth between 641.4 and 664 ft bgs (Sample ID: GW34-04-53519). A sample of the water used for drilling was also collected for chemical screening (Sample ID: GW34-04-53520). This sample was collected directly from the on-site water storage tank. The source for this water is the fire hydrant located across from Building 52-117. A groundwater sample (Sample ID GW34-04-53521) was obtained from the screened interval (883.7 to 906.6 ft bgs) during later stages of well development on September 2, 2004. All samples were submitted to LANL for analysis.

4.3 Geochemistry of Sampled Waters

The analytical results for the samples collected are presented and discussed in Appendix A. The results of the chemical analyses for the aqueous sample collected from 641.4 to 664 ft bgs indicate that the sample was not perched groundwater, but rather a mix of drilling fluids and makeup water. The screening groundwater sample collected from the regional aquifer between 883.7 and 906.6 ft bgs was collected primarily to determine if potential contaminants were present in the regional aquifer. Major potential contaminants of concern at R-34 include mobile solutes such as nitrate, perchlorate, uranium, and tritium. Concentrations of tritium and perchlorate were less than detection and the concentration of nitrate (N) was less than 0.5 ppm, which is typically observed in supply wells at the Laboratory. Please see Appendix A for the screening analytical results from this sample.

5.0 BOREHOLE LOGGING

Using LANL-owned and subcontractor-owned tools, KA and Schlumberger performed borehole video and geophysical logging at R-34. Video logs and geophysical logs are included in Appendix B and Appendix C, respectively.

5.1 Video Logging

Video logging of the R-34 borehole was performed by KA on July 25, 2004 using LANL equipment; LANL employees conducted the August 4 and August 10, 2004 surveys. A separate video logging operation was also performed within the completed well after its construction.

On July 25, 2004, video logging was performed to evaluate the condition of the borehole to a depth of about 424 ft bgs. The video log showed a void as well as a bridge. This resulted in the placement of a sand and concrete plug to stabilize the borehole from 302 ft to 417 ft bgs.

On August 4, 2004, video logging was performed to evaluate the cause of the difficulties encountered earlier by Schlumberger while attempting to perform geophysical logging of the open borehole to the TD of 1,065 ft bgs. At a depth of about 388 ft bgs, the video camera image showed that two separate boreholes had developed. The camera was lowered into the more downgradient side of the two boreholes. An interface of foam and liquid was then encountered by the camera at a depth of about 640 ft bgs. The camera was lowered into the foam and liquid but the image quality was unsatisfactory and the camera was withdrawn to the bridge at a depth of 388 ft bgs. The camera was then advanced down the second borehole to a depth of 465 ft bgs, where the bottom of the hole was encountered. No foam or liquid was observed, and the camera was withdrawn to the ground surface.

Video logging was again performed on August 10, 2004. This third operation was performed after casing had been installed into the borehole to a depth of 739 ft bgs. The video logging was performed after the second successful attempt to perform geophysical logging on this same date (see Section 5.2). The video camera was advanced beyond the bottom of the casing and to a depth of about 796 ft bgs. During this operation, foam was observed at a depth of 782 ft bgs and water was observed at a depth of 796 ft bgs, at which point the camera was withdrawn to the ground surface.

The final video log was performed by LANL on September 18, 2004 as an as-built survey of the completed well. The video camera was operated between 0 ft and 917 ft bgs.

Video logging was used to identify potential perched water zones, to aid in lithologic contact identification, and to identify portions of the borehole where drilling problems were encountered. The final video log did not show visible evidence of any perched water zones in the borehole. The video log of the open borehole was digitized onto a digital video disc (DVD) and is included as Appendix B.

5.2 Geophysical Logging

The primary purpose of the geophysical logging was to characterize the conditions in the hydrogeologic units penetrated by the R-34 borehole, with emphasis on gathering moisture distribution data, identifying water-bearing zones, measuring capacity for flow (porosity and moisture), and obtaining lithologic/stratigraphic data. Secondary objectives included evaluating borehole geometry and determining the degree of drilling fluid invasion along the borehole wall.

Schlumberger personnel used a suite of geophysical logging tools in the cased and uncased portions of the borehole. Descriptions and uses for each of the geophysical logging tools are presented in Appendix C.

Schlumberger personnel conducted geophysical logging of the R-34 borehole on two separate occasions. Geophysical logging was first attempted on August 3, 2004 after the borehole had been drilled to the TD of 1,065 ft bgs. The tool was lowered into the borehole but encountered difficulty penetrating below a depth of 692 ft bgs. After discussions with DOE personnel, the decision was made to conduct the geophysical logging from this depth to the ground surface.

Table 5.2-1
Borehole Logging Conducted

Operator	Date	Cased Footage (ft bgs)	Open-hole Interval (ft bgs)	Remarks	Tools
KA/LANL	July 25, 2004	0-59	60-693	Used to evaluate hole	Video Camera
Schlumberger	August 3, 2004	0-59[(a)]	59[(a)]-693	Perform geophysical logging to 693 ft	Triple Litho Density Compensated Neutron Log Gamma Ray-Caliper
LANL	August 4, 2004	0-59	59-693	Performed to evaluate cause of difficulty with geophysical logging	Video Camera
Schlumberger	August 9-10, 2004	0-739[(b)]	739[(b)]-935	Perform geophysical logging from 0 to 935 ft	Combinable Magnetic Resonance Elemental Capture Sonde Triple Litho Density Compensated Neutron Log Gamma Ray Caliper Natural Spectroscopy Gamma Ray Array Induction Gamma Ray
LANL	August 10, 2004	0-739	739-935	Video logging in open borehole to identify perched water in the zone of saturation	Video Camera
LANL	September 18, 2004	0-927	N/A	Evaluate as-built condition of completed well	Video Camera

[(a)] Schlumberger reported the depth to the bottom of the surface casing as 60 ft bgs.
[(b)] Schlumberger reported the depth to the bottom of the borehole casing as 740 ft bgs.

The second attempt to perform geophysical logging of the borehole took place on August 9 and 10, 2004. This work was performed after the drive casing had been installed into the borehole to a depth of 739 ft bgs and after the borehole had been reamed to the original TD of 1,065 ft bgs. The tool was lowered into the borehole early on the morning of August 10 after a significant quantity of foam drilling fluid had been ejected out of the borehole. An obstruction was encountered, and the tool could be lowered to a depth of only about 935 ft bgs. DOE personnel were consulted, and it was decided to perform geophysical logging from this depth. As successive logging runs were performed, the borehole continued to slough and the depth of logging decreased from a maximum of 921 to a minimum of 878 ft bgs for the natural spectroscopy gamma ray. After the last logging run, the tool was withdrawn to the ground surface, and Schlumberger personnel demobilized from the site.

Table 5.2-1 summarizes the logging conducted in the R-34 borehole by Schlumberger, KA, and LANL. Schlumberger's report is presented in Appendix C along with the interpretive logging report and the geophysical logs, compiled as a montage (provided on the CD attached).

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary description of the hydrogeologic features encountered during drilling operations at R-34 is presented below. Included are summary descriptions of geologic units identified during characterization of the cuttings sampled and a review of geophysical logs. LANL EES-6 staff provided preliminary interpretation of geologic contact zones. Several of the geologic units encountered during drilling were relatively unstable, resulting in significant periods of lost circulation and producing sections of poor or intermixed cuttings and limited intervals for geophysical logging. Stratigraphic contacts are based on available information. Groundwater occurrences are interpreted from drilling evidence, open-hole video logging, geophysical logging, and water-level measurements.

6.1 Stratigraphy and Lithology

Rock units and stratigraphic relationships are interpreted based on visual examination of the borehole drill cutting samples, as well as preliminary interpretations of the geophysical data, and are briefly discussed in order of younger to older occurrence. The drill cuttings from R-34 commonly are mixtures of cuttings derived from one or more geologic units. In addition, poor circulation of drilling fluids resulted in long intervals in which no cuttings were returned to the surface. Because of these problems, the borehole geophysical logs were particularly useful for identifying geologic contacts. The interpretations presented below are preliminary and may be revised upon additional analysis of petrographic, geochemical, mineralogical, and geophysical logging data. A lithologic log of the borehole containing detailed descriptions that identify the texture and composition of sample intervals is presented in Appendix D.

Alluvium, Qal (0 to 18 ft bgs)

Cuttings collected from the borehole indicate that unconsolidated alluvium exists from the ground surface to approximately 18 ft bgs. The position of the contact between the alluvium and the Tshirege Member of the Bandelier Tuff is uncertain, and additional geologic characterization is underway to identify this contact. Samples collected from 0 to 18 ft bgs consisted of silt with sands and gravels typically composed of volcanic lithics, tuff fragments, and quartz crystals. The composition is comparable to that of the Bandelier Tuff, from which these sediments are likely derived.

Tshirege Member, Bandelier Tuff, Qbt1g (18 to 96 ft bgs)

The lower vitric unit of the Tshirege Member of the Bandelier Tuff was encountered in the borehole between 18 and 96 ft bgs. The tuff is grayish to pale orange, poorly welded, and pumice-rich. The coarse fraction (i.e., the >#10 sieve size) of most cuttings samples in this interval is made up of vitric, fibrous pumices. The fine fraction (i.e., the >#35 sieve size) is made up of pumices and tuff fragments, quartz and sanidine crystals, and a small percentage of lithics.

Otowi Member, Bandelier Tuff, Qbo (96 ft to 134 ft bgs)

Rhyolitic ash-flow tuff representing the Otowi Member of the Bandelier Tuff was intersected in the borehole from 96 to 134 ft bgs. Cuttings showed that the Otowi Member is locally pumiceous, lithic-bearing, and poorly welded. The coarse fraction of most cuttings samples from this interval is made up of predominantly volcanic lithic fragments of intermediate volcanic composition including iron-stained dacite, vitric pumices, and a very small fraction of crystals. Fine-fraction samples are made up predominantly of quartz and sanidine crystals, with subordinate amounts of volcanic lithics and pumice.

Guaje Pumice Bed, Bandelier Tuff, Qbog (134 ft to 146 ft bgs)

The Guaje Pumice Bed, encountered from 134 to 146 ft bgs, is made up of pumice-fall deposits that form the basal subunit of the Otowi Member of the Bandelier Tuff. Cuttings from the interval were severely milled in the process of drilling, to the extent that there was very little recovery of the coarse fraction, indicating the friable nature of this unit. The fine fraction is predominantly (i.e., more than 50 percent by volume) vitric pumice with subordinate amounts of quartz and sanidine crystals, as well as lithic fragments of intermediate volcanic composition.

Cerros del Rio Basalt, Tb (146 to 678 ft bgs)

The Cerros del Rio basalt, comprising basaltic lavas and intercalated scoria deposits, was encountered in the borehole from 146 to 678 ft bgs. Cuttings indicated that the upper portion of this section, from 148 to about 298 ft bgs, consists of medium to dark gray, massive to vesicular basaltic lava that contains occasional phenocrysts in an aphanitic groundmass. The groundmass exhibits minor weathering and/or alteration. Below 298 ft bgs, distinctive reddish intervals of oxidized scoriaceous basaltic cinders occur to 610 ft bgs. The interval again changed back to medium blue-gray massive basaltic lava from 610 to 678 ft bgs.

Older Alluvium, Ta (678 to 725 ft bgs)

Volcaniclastic sediments consisting of silty gravel and broken to rounded gravel clasts were encountered from 678 to 725 ft bgs in the borehole. The clasts were composed of basalt, scoria, and various intermediate volcanic composition clastic rocks and quartzite that were subrounded to rounded.

Puye Formation, Pumiceous subunit, Tpp (725 to 1,050 ft bgs)

The Puye Formation provided sporadic sample returns of pumiceous volcaniclastic constituents including abundant pumices with minor amounts of detrital clasts of intermediate volcanic composition. Large intervals of poor recovery of cuttings were encountered in this unit. Geophysical logs suggest that the upper part of the unit, from 725 – 790 ft bgs, may be Puye fanglomerate similar to that found below Cerros del Rio basalt in deep wells in nearby Mortandad Canyon.

Puye Formation, Totavi Lentil subunit, Tpt (1,050 to 1,065 ft bgs)

Due to lack of geophysical logs and poor cutting returns, the Totavi Lentil interval thickness is estimated. Available cuttings collected by circulation at TD indicate the presence of Precambrian granitic clasts, quartzite, and varied intermediate volcanic composition clasts that are rounded to subrounded. Sample chips also include scoria and pumice fragments obtained from overlying formations.

6.2 Groundwater Occurrence and Characteristics

The SAP indicated that there was a possibility regional groundwater would be encountered in the Puye Formation at approximately 915 ft bgs.

During borehole drilling, one aqueous sample (GW34-04-53519) was collected from a depth between 641.4 and 664 ft bgs to determine if perched groundwater was present. A groundwater sample (Sample ID GW34-04053521) was collected near the end of well development from the screened interval (883.7 to 906.6 ft bgs).

The processed geophysical logs indicate a significant increase in water saturation below 794 ft bgs, which is consistent with the water level in the well at the time of the logging. The estimated pore volume water saturation (fraction of the total pore volume containing water) computed from the ELAN (Elemental Analysis) is high (above 75 percent) from 794 ft bgs to the bottom of the logged interval (933 ft bgs), compared with 40 to 65 percent in the interval directly above 794 ft bgs. The estimate is even higher when computed directly from bulk density and ELAN water-filled porosity for a grain density range of 2.45 to 2.65 grams per cubic centimeter (g/cc), ranging from 80 percent (2.65 g/cc) to consistently 90 to100 percent (2.45 g/cc). These results suggest that the static water level for the regional aquifer occurs at 794 ft bgs. After completion of drilling on August 10, 2004, the DTW was again measured in the open borehole and was found to be at 796.17 ft bgs. Prior to aquifer testing, on September 11, 2004 the static water level was measured at 796 ft bgs.

KBr was added to the drilling fluid as a tracer to aid in determining perched and regional groundwater. The KBr tracer was introduced using a bromide injection system. Results of sampling and analysis for KBr indicate that the initial injection concentration was too low. Bromide concentrations began to decrease at approximately 270 ft bgs, as shown in Figure 6.2-1. Due to the low concentration and lost circulation, samples were not taken between about 340 to 600 ft bgs. The problem with the injection system was repaired, and tracer was again added to the system from a depth of about 600 to 700 ft bgs. The final results of sampling and analysis for the KBr injection tracer do not indicate groundwater over the depth interval evaluated.

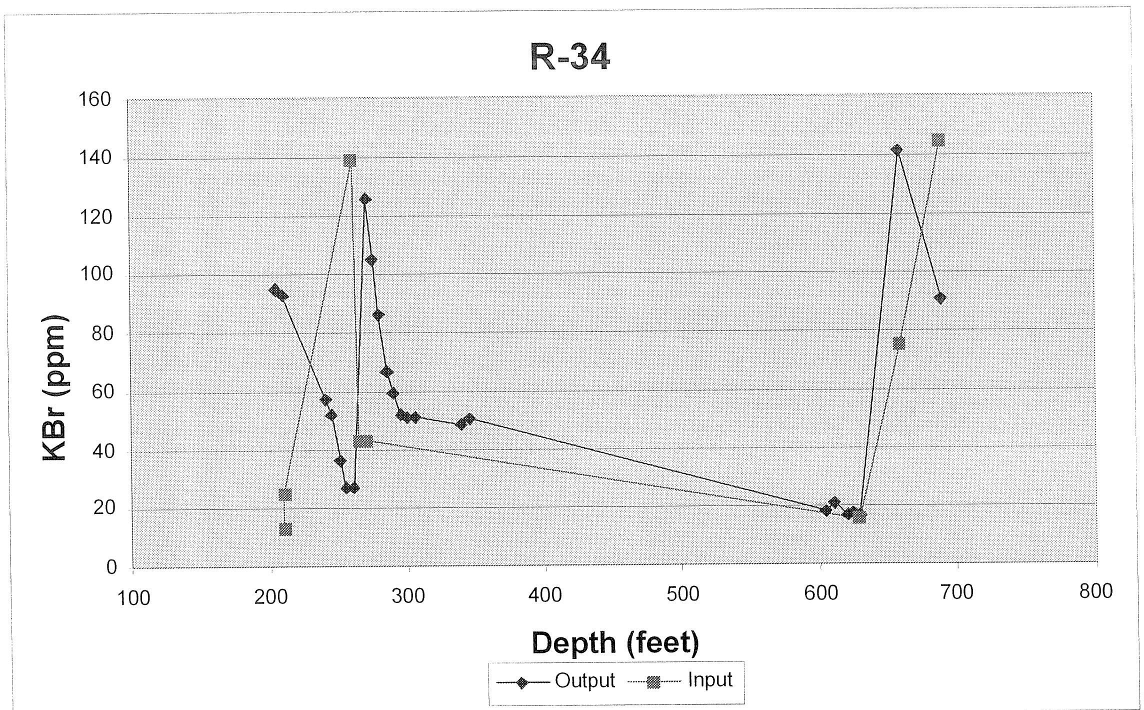


Figure 6.2-1. KBr Concentrations in Borehole During Drilling

7.0 WELL DESIGN AND CONSTRUCTION

R-34 was installed as a hydrogeologic characterization and groundwater monitoring well. Following approval of the well design by DOE, LANL and the New Mexico Environment Department (NMED), KA received the final construction specifications for R-34 on August 11, 2004. Well installation activities were performed from August 13 to September 20, 2004.

7.1 Well Design

Data from geophysical logs and borehole cuttings, as well as field water level measurements and field observations, were evaluated to determine the screen placement interval for the well. Design of the well was performed in accordance with LANL ER SOP-05.01, Revision 3 and an approved well design was provided to KA by DOE and LANL. The well was designed with a single screen interval to monitor potential contaminants and groundwater chemistry in the uppermost productive zone of the regional aquifer in the Puye Formation.

7.2 Well Construction

R-34 was constructed of 4.5-inch inner diameter (ID)/5.0-inch OD, type A304, stainless-steel casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. Two nominal 12-ft lengths of 5-in OD compatible, 0.020-inch rod-based wire-wrapped well screens were also used. The casing and screens were factory cleaned before shipment and delivery to the site. Additional decontamination of the stainless-steel components was performed on site prior to well construction using a high-pressure steam cleaner. The screened interval chosen for the well was 883.7 to 906.6 ft bgs. Stainless steel casing was placed below the screen to construct a 14.1 ft-deep sump. External couplings, also of type A304 stainless steel fabricated to ASTM A312 standards, were used to connect individual casing and screen joints. The $9\frac{5}{8}$-inch drill casing remained in the borehole during well construction of the screened interval to maintain hole stability. Centralizers were not able to pass through the drill casing and thus were not used in the well. Figure 7.2-1 is an as-built schematic of the completed well.

Placement of annular fill into the borehole consisted of using a 2.5-inch OD steel tremie pipe to deliver various materials to specified backfill intervals. It was determined based on sounding that approximately 90 ft of formation material had sloughed into the borehole from the TD of 1,065 up to 975 ft bgs. From 975 up to 935 ft bgs, a mixture of 8/20 silica sand and bentonite was placed as the foundation for the filter pack above. Well casing and screens were lowered in the borehole. A primary filter pack consisting of 8/20 silica sand was placed across the screened interval from 935 up to 877 ft bgs. A secondary filter pack of 20/40 silica sand was placed above the primary filter pack from 877 up to 875 ft bgs. Prior to placement, filter pack materials were mixed with municipal water to form a slurry. The filter pack was then swabbed to induce settling prior to bentonite placement. Next, a seal consisting of a mixture of 8/20 sand and bentonite chips was placed above the secondary filter pack in the annular space between 875 and 717 ft bgs. The $9\frac{5}{8}$-inch drill casing was pulled, resulting in a shift upward of the well casing of approximately 3.4 feet (final well component depths are reflected on Figure 7.2-1). During retraction of the drill casing, another formation collapse occurred, filling in the annular space from 717 up to 667 ft bgs. Between 667 and 82 ft bgs, the annular space was filled with a mixture of 70 percent bentonite and 30 percent 8/20 sand. The bentonite mixture was hydrated in approximately 50-ft lifts. After removing the $13\frac{3}{8}$-in conductor casing, concrete backfill, consisting of 2,500 pounds per square inch (psi) concrete, was placed from 82 ft bgs to ground surface. Quantities of annular fill materials used are presented in Table 7.2-1.

TOTAL LENGTH OF CASING AND SCREEN 922.72 FT

PROTECTIVE CASING LOCKING COVER

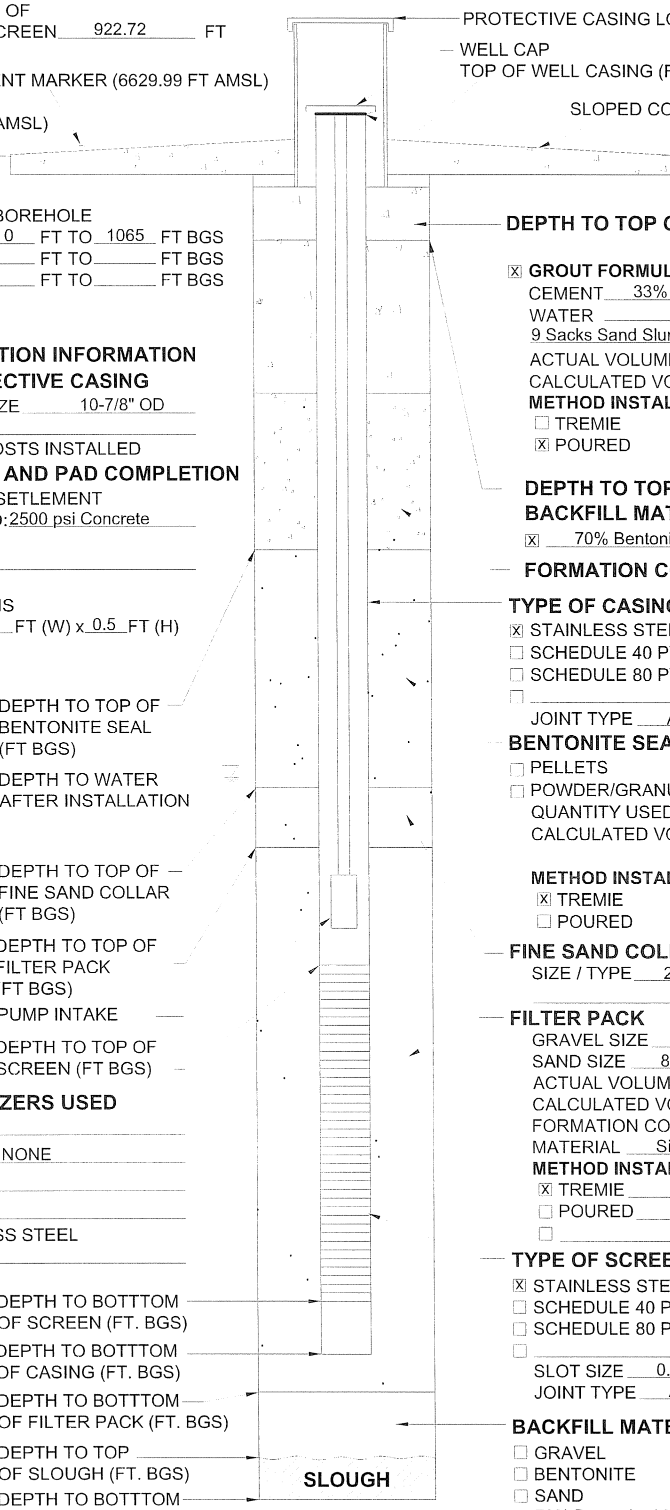
WELL CAP

TOP OF WELL CASING (FT AMSL) 6632.01

MONUMENT MARKER (6629.99 FT AMSL)

GROUND SURFACE (6629 FT AMSL)

SLOPED CONCRETE PAD / SURFACE SEAL



DIAMETER OF BOREHOLE
12-1/4" FROM 0 FT TO 1065 FT BGS
_____ FROM _____ FT TO _____ FT BGS
_____ FROM _____ FT TO _____ FT BGS

DEPTH TO TOP OF SURFACE SEAL (FT BGS) 0.7

[X] **GROUT FORMULA (PROPORTION OF EACH)**
CEMENT 33% BENTONITE 5%
WATER _____ OTHER 2% $CaCl_2$; 60% Sand
9 Sacks Sand Slurry
ACTUAL VOLUME 114.8 ft^3
CALCULATED VOLUME 55.3 ft^3
METHOD INSTALLED
[ ] TREMIE [ ] _____
[X] POURED [ ] NOT USED

SURFACE COMPLETION INFORMATION

TYPE OF PROTECTIVE CASING

[X] STEEL SIZE 10-7/8" OD
[ ] _____
[X] PROTECTIVE POSTS INSTALLED

SURFACE SEAL AND PAD COMPLETION

[X] CHECKED FOR SETLEMENT
MATERIAL USED: 2500 psi Concrete
REINFORCED
[X] YES: Rebar
[ ] NO
PAD DIMENSIONS
5 FT (L) x 5 FT (W) x 0.5 FT (H)

DEPTH TO TOP OF BACKFILL MATERIAL (FT BGS) 82
[X] 70% Bentonite / 30% 8/20 Sand

FORMATION COLLAPSE (FT BGS) 667 - 717

TYPE OF CASING
[X] STAINLESS STEEL CASING DIAMETER
[ ] SCHEDULE 40 PVC INSIDE 4.5 in.
[ ] SCHEDULE 80 PVC OUTSIDE 5.0 in.
[ ] _____
JOINT TYPE API Long Thread

717 DEPTH TO TOP OF BENTONITE SEAL (FT BGS)

796 DEPTH TO WATER AFTER INSTALLATION

BENTONITE SEAL
[ ] PELLETS [ ] SLURRY
[ ] POWDER/GRANULAR [X] Chips + 8/20 Sand
QUANTITY USED 1226.1 ft^3
CALCULATED VOLUME 397.8 ft^3

METHOD INSTALLED
[X] TREMIE [ ] _____
[ ] POURED [ ] NOT USED

875 DEPTH TO TOP OF FINE SAND COLLAR (FT BGS)

877 DEPTH TO TOP OF FILTER PACK (FT BGS)

881.6 PUMP INTAKE

883.7 DEPTH TO TOP OF SCREEN (FT BGS)

FINE SAND COLLAR (OPTIONAL)
SIZE / TYPE 20/40 Sand

FILTER PACK
GRAVEL SIZE _____
SAND SIZE 8/20
ACTUAL VOLUME 27.5 ft^3
CALCULATED VOLUME 41.0 ft^3
FORMATION COLLAPSE: _____ TO _____ FT BGS
MATERIAL Silica Sand
METHOD INSTALLED
[X] TREMIE
[ ] POURED
[ ] _____

CENTRALIZERS USED
[ ] YES AT _____
NONE

[ ] STAINLESS STEEL
[X] No

TYPE OF SCREEN
[X] STAINLESS STEEL SCREEN DIAMETER
[ ] SCHEDULE 40 PVC INSIDE 4.5 in.
[ ] SCHEDULE 80 PVC OUTSIDE 5.0 in.
[ ] _____
SLOT SIZE 0.02 in. Wire Wrap
JOINT TYPE API Long Thread

906.6 DEPTH TO BOTTTOM OF SCREEN (FT. BGS)

920.7 DEPTH TO BOTTTOM OF CASING (FT. BGS)

935 DEPTH TO BOTTTOM OF FILTER PACK (FT. BGS)

975 DEPTH TO TOP OF SLOUGH (FT. BGS)

1065 DEPTH TO BOTTTOM OF BORING (FT. BGS)

BACKFILL MATERIAL
[ ] GRAVEL [X] FORMATION COLLAPSE (975 - 1065 ft bgs)
[ ] BENTONITE MATERIAL _____
[ ] SAND
[X] 70% Bentonite / 30% 8/20 Sand

WELL COMPLETION BEGAN
DATE 8/13/04 TIME 07:00

WELL COMPLETION FINISHED
DATE 8/20/04 TIME 17:00

WELL DEVELOPMENT INFORMATION

DEVELOPMENT METHOD
[X] SWABBING [X] BAILING
[X] PUMPING
TOTAL PURGE VOLUME 34,120 GALLONS

FINAL PARAMETER MEASUREMENTS
pH 8.11
TEMPERATURE 20.7 °C
SPECIFIC CONDUCTANCE 189 µS
TURBIDITY 3.7 NTU

KLEINFELDER

Scale: Not-To-Scale
Drawn By: C. Landon
Project No.: 37151

Date: September 2004
Filename: Figure 7.2-1.dwg

WELL SCHEMATIC
Characterization Well R-34
San Ildefonso Pueblo
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
7.2-1

G:\Environ\37151 - DOE Deep Wells\R-34\Fact Sheet

Table 7.2-1
Annular Fill Materials Used in Well Construction

Material	Volume	Mix [a]
Backfill: bentonite and 8/20 silica sand	16.1 ft^3	70:30
Primary Filter: 8/20 silica sand	27.5 ft^3	-
Fine Sand Collar: 20/40 silica sand	2.0 ft^3	-
Bentonite Seal below groundwater: bentonite chips and 8/20 silica sand	183.2 ft^3	70:30
Bentonite Seal above groundwater: bentonite chips	1226.1 ft^3	70:30
Surface Seal: cement slurry	114.8 ft^3	Portland with up to 5% bentonite
Potable Water	26,107 gal (approx.) [b]	-
Backfill [c] : 8/20 silica sand	90.0 ft^3	-
Backfill [c] : cement slurry	891.0 ft^3	
Backfill [c] : bentonite	80.4 ft^3	-
Backfill [c] : potable water	200 gal (approx.)	

[a] A ratio of mixture by volume
[b] Approximation based on geologist log
[c] Borehole repair on 7/27/04 due to formation collapse

8.0 WELL DEVELOPMENT AND AQUIFER TESTING

Well development activities were conducted from August 27 to September 2, 2004. Well development procedures included well screen swabbing, bailing, and pumping. Aquifer testing, consisting of a constant-rate pumping and recovery test, began on September 14 and was completed on September 16. A total of 50,972 gallons of water were removed during well development and aquifer testing activities.

8.1 Well Development

Well development was performed in two stages. The initial stage consisted of bailing and swabbing the screened interval and sump to remove bentonite materials, drilling fluids, and formation sands and fines that had been introduced into the well during drilling and installation. Bailing activities were conducted by WDC using a 3.5-gallon (gal) capacity, 3-inch OD by 10-ft-long stainless steel bailer. Bailing activities continued until water clarity improved. Bailing was followed by swabbing across the screened interval to enhance filter-pack development. The swabbing tool consisted of a 4.25-inch OD, 1-inch-thick rubber disc attached to the drill rod that was lowered into the well and drawn repeatedly across the screened interval for approximately 1 hour. Water turbidity was not measured during the bailing and swabbing process.

Following swabbing, pumping development procedures were applied to the screened interval using a 7.5-horsepower, 4-inch Grundfos submersible pump. The pump intake was lowered to the screened interval and cycled on at a nominal rate of approximately 20 gallons per minute (gpm). The pump intake was then drawn across the length of the screened interval. During pumping, water samples were collected to measure water quality parameters.

Criteria for well development were based on field measurements of water quality parameters (pH, temperature, specific conductance, and turbidity). Total Organic Carbon (TOC) measurements were not obtained because the LANL safety and security shutdown was in effect during the time of well development. To monitor progress during each development stage, samples of water were periodically collected and parameter measurements were recorded. The primary objective of well development was to remove suspended sediment from the water until turbidity, measured in nephelometric turbidity units (NTU), was less than 5 NTUs for three consecutive samples. Measured parameters were required to stabilize before termination of development procedures. Table 8.1-1 presents the data for the water quality parameters measured during the well development process. The cumulative effects of well development on water quality are presented graphically in Figure 8.1-1.

Table 8.1-1
Water Removed and Final Water Quality Parameters
During Well Development and Aquifer Testing

Method	Water Removed (gal)	pH	Temperature (°C)	Specific Conductance (mS/cm) [a]	Turbidity (NTU)
Bailing/ Swabbing Screen	50	7.76	22.80	0.43	NM
Pumping Screen	34,070	8.11	20.70	0.19	3.70
Aquifer Testing	16,852	NM	NM	NM	NM
Total	**50,972**	–	–	–	–

[a] Specific conductance is reported in milliSiemens per centimeter (mS/cm).
[b] NM = Not Measured

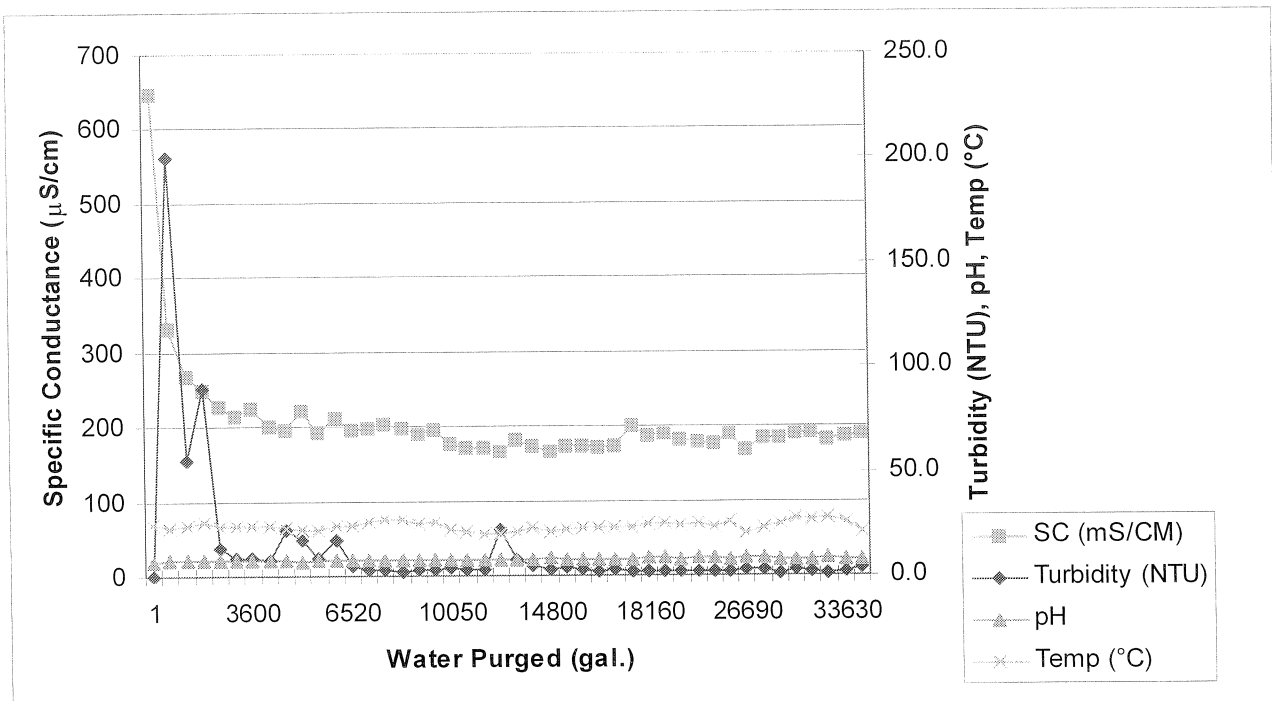


Figure 8.1-1. Effects of Well Development on Water Quality Parameters

8.2 Aquifer Testing

Constant-rate pumping tests were performed on R-34. A summary of the pump tests and accompanying data are presented in Appendix E.

8.3 Dedicated Sampling System Installation

A 2-horsepower Grundfos submersible pump was installed in R-34 between October 29 and November 2, 2004. The pump is rated at 5 gallons per minute and the pump intake is set at 881.6 ft bgs.

8.4 Wellhead Completion

On August 25, 2004, a reinforced (2,500 psi) concrete pad, 5 ft wide by 5 ft long by 6 in. thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 10.75-inch steel casing with locking lid protects the well riser. The pad was designed to be slightly elevated, with base course graded up around the pad to allow for drainage.

8.5 Geodetic Survey

The location of the well was determined by geodetic survey on September 10, 2004. Lynn Engineering and Surveying, Inc. conducted the survey. Coordinates and elevations were obtained from LANL Monument MCOBT-4.4 using static Global Positioning System (GPS) observation.

This survey located the brass cap monument at the well in the concrete pad and the top of the stainless steel well casing and borehole. Table 8.5-1 summarizes the readings recorded for these components of the completed wellhead. The coordinates shown are New Mexico State Plane Grid Coordinates, Central Zone (North American Datum of 1983 [NAD 83]), expressed in feet. Elevation is expressed in feet above mean sea level relative to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Table 8.5-1
Geodetic Data

Description	Northing	Easting	Elevation [a]
Brass cap in R-34 pad	1764028.77	1643595.82	6629.99
Top of stainless-steel casing	1764027.86	1643597.44	6632.01

[a] Measured in feet above mean sea level (amsl) relative to the National Geodetic Vertical Datum of 1929.

8.6 Site Restoration

Fluids and cuttings produced during drilling and development were sampled in accordance with the "Notice of Intent (NOI) to Discharge, Hydrogeologic Workplan Wells," and filed with the NMED. Approval to discharge drilling and development water was received from NMED on November 10, 2004. A copy of the NMED discharge approval, as well as the sample analytical results, is included in Appendix F.

Temporary fencing and straw bales have been left in place to minimize possible erosion and sedimentation impacts from future precipitation.

Future site restoration activities will include (1) removal and land application of water from the borehole-cuttings containment area, (2) removal of the polyethylene liner and borehole cuttings from the borehole-cuttings containment area, (3) removal of the containment area berms, and (4) backfilling and grading of the containment area. The cuttings will be thinly spread over the site after NMED approval has been obtained. Site reseeding will be performed in Spring 2005.

9.0 DEVIATIONS FROM THE SAP

Appendix G compares the actual drilling and well construction activities performed at R-34 with the planned activities described in the SAP (LANL 2003, LAUR-03-8324). For the most part, drilling, sampling, and well construction at R-34 was performed as specified in the SAP. The main deviations from planned activities are summarized as follows:

- Planned Borehole Depth – The SAP stipulated that the borehole be drilled to a TD of 1,015 ft bgs, or approximately 100 ft below the regional water table that was projected to occur at 915 ft bgs. At the direction of DOE personnel, the well was drilled deeper because of uncertainties at that time about the depth to the regional zone of saturation. The increased depth will also accommodate 50 years of projected drawdown from nearby production wells. The completed R-34 borehole was drilled to a TD of 1,065 ft bgs, which was 269 ft below the measured depth to the regional water table (796 ft bgs) determined on September 11, 2004.

- Depth to Regional Aquifer – The SAP identified the approximate depth to the regional aquifer as 915 ft bgs. The depth to the regional aquifer measured in the completed well on September 11, 2004 was 796 ft bgs.

10.0 ACKNOWLEDGMENTS

D. Schafer of Schafer and Associates contributed the aquifer testing section of this report.

N. Bailey and J. Hurley of Tetra Tech EM Inc. contributed to the preparation of this report.

EnviroWorks, Inc. provided site preparation and restoration activities.

Lynn Engineering & Surveying, Inc. provided the final geodetic survey of finished well components.

N. Clayton of Schlumberger provided processing and interpretation of borehole geophysical data.

P. Longmire of Los Alamos National Laboratory contributed the geochemistry section of this report.

Tetra Tech EM Inc. provided support for site geology, sample collection, and aquifer testing.

WDC Exploration & Wells provided rotary drilling services.

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LANL (Los Alamos National Laboratory) 2004. Teleconference Call with Pat Longmire Regarding Geochemistry of Sampled Waters, March 16, 2004.

Appendix A

Groundwater Analytical Results

1.0 GEOCHEMISTRY OF SAMPLED WATERS

Alluvial, intermediate, and regional groundwater can potentially be encountered in the subsurface at LANL. Alluvial groundwater was not encountered at borehole R-34. One aqueous sample was collected from the borehole at an intermediate depth between 641.4 and 664 feet below ground surface (ft bgs). The regional water table was encountered at 796 ft bgs, and a groundwater sample was collected at a depth range of 883.7 to 906.6 ft bgs during well development on September 2, 2004. Additionally, a water sample was collected from the onsite surface water tank.

1.1 ANALYSES

The aqueous samples collected from the intermediate depth in the borehole (GW34-04-53519) and from the surface water tank (GW34-04-53520) were analyzed for major ions, calcium, magnesium, potassium, silica, sodium, inorganic chemicals, and total dissolved solids. The same suite of analyses, plus radionuclide analyses and total organic carbon (TOC), were conducted on the groundwater sample from the regional aquifer (GW34-04-53521).

The water samples were analyzed by EES-6 using techniques specified in the US Environmental Protection Agency SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The method detection limit for perchlorate using IC is 0.002 parts per million (ppm), or milligrams/liter (L) (equivalent to 2 parts per billion, or 2 micrograms/L). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for calcium, magnesium, potassium, silica, and sodium. Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, uranium, and zinc were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS).

Radionuclide activity in the sample from the regional aquifer (GW04-34-53521) was determined by direct counting for tritium; alpha spectrometry for americium, plutonium, and uranium isotopes; gas proportional counting for strontium-90; and gamma spectrometry for cesium-137 and other gamma-emitting isotopes by GEL (radionuclides) and the University of Miami (low-level tritium) laboratories. Stable isotopes of oxygen (oxygen-18 and oxygen-16, $\delta 18O$), hydrogen (hydrogen and deuterium, δD), and nitrogen (nitrogen-15 and nitrogen-14, $\delta 15N$) are being analyzed by EES-6 using isotope ratio mass spectrometry; analytical results for the stable isotopes are pending for R-34. The precision limits (analytical error) for major ions and trace elements were generally less than $\pm 10\%$ using ICPES and ICPMS.

1.2 ANALYTICAL RESULTS

The analytical results from the water sample (GW34-04-53519) collected from the R-34 borehole from between 641.4 and 664 ft bgs on August 5, 2004, and analytical results are provided in Table 1.1. This water sample contained 3.21 ppm of bromide, 12.3 ppm of chloride, 0.43 ppm of fluoride, 0.03 ppm of nitrite (as nitrogen [N]), 0.01 ppm of phosphate (as phosphorus), 39.4 ppm of sulfate, and concentrations of nitrate and perchlorate were less than detection. This water sample most likely represents a mixture of drilling fluids and drilling surface water. Potassium bromide was added as a tracer during drilling to identify perched

Table 1.1 Analytical Results of Borehole Water and Surface Tank at Well R-34 (filtered samples)

Sample ID Number	**GW34-04-53519**	**GW34-04-53521**	**GW34-04-53520**
Depth (ft)	**641.4 to 664 feet**	**883.7 to 906.6 feet**	**Surface Water Tank**
Geologic Unit	**Cerros del Rio Basalt**	**Puye Formation (Pumiceous Subunit)**	**Not Applicable**
Date Sampled	**08/05/04**	**09/02/04**	**08/06/04**
Charge Balance (%)	+6.24	3.7	-1.48
pH (Lab)	7.30	8.11	7.18
Alkalinity (ppm $CaCO_3$/L)	145	80.8	72.5
Al (ppm)	4.15	0.13	0.003
Sb (ppm)	[0.001], U	[0.001], U	[0.001], U
As (ppm)	0.008	0.011	0.036
B (ppm)	0.038	0.023	0.028
Ba (ppm)	0.12	0.024	0.03
Be (ppm)	[0.001], U	[0.001], U	[0.001], U
HCO_3 (ppm)	177	98.6	88.4
Br (ppm)	3.21	0.20	34.4
Cd (ppm)	[0.001], U	[0.001], U	[0.001], U
Ca (ppm)	52.2	16.6	13.4
Cl (ppm)	12.3	2.74	3.72
ClO_4 (ppm) (IC)	[0.001], U	[0.001], U	[0.0005], U
Cr (ppm)	0.0041	0.0046	0.0032
Co (ppm)	0.0023	[0.001], U	[0.001], U
Cu (ppm)	0.0039	0.0016	0.0047
F (ppm)	0.43	0.36	0.27
Fe (ppm)	1.79	0.08	0.27
Pb (ppm)	0.0020	0.0002	0.0009
Mg (ppm)	10.8	3.73	4.10
Mn (ppm)	0.50	0.024	0.0048
Hg (ppm)	0.00016	[0.00005], U	0.00015

Notes:
U = not detected
IC = ion chromatography
Silica concentrations were calculated from measured silicon (ICPES).
Bicarbonate concentrations were calculated from measured alkalinity .

Sample ID Number	**GW34-04-53519**	**GW34-04-53521**	**GW34-04-53520**
Depth (ft)	**641.4 to 664 feet**	**883.7 to 906.6 feet**	**Surface Water Tank**
Geologic Unit	**Cerros del Rio Basalt**	**Puye Formation (Pumiceous Subunit)**	**Not Applicable**
Date Sampled	**08/05/04**	**09/02/04**	**08/06/04**
Mo (ppm)	0.025	0.0016	0.0017
Ni (ppm)	[0.001], U	[0.001], U	[0.001], U
NO_3 (ppm) (as N)	[0.002], U	0.39	[0.002], U
NO_2 (ppm) (as N)	0.03	[0.01], U	[0.01], U
C_2O_4 (ppm) (oxalate)	[0.01], U	[0.01], U	[0.01], U
PO_4 (ppm) (as P)	0.01	0.01	0.01
K (ppm)	7.06	2.27	17.9
Se (ppm)	0.004	[0.001], U	[0.001], U
Ag (ppm)	[0.001], U	[0.001], U	[0.001], U
Na (ppm)	16.1	12.0	12.9
SiO_2 (ppm)	69.0	66.2	82.7
Sr (ppm)	0.23	0.067	0.070
SO_4 (ppm)	39.4	4.03	3.72
Tl (ppm)	[0.001], U	[0.001], U	[0.001], U
U (ppm)	0.0031	0.0007	0.0005
V (ppm)	0.008	0.009	0.007
Zn (ppm)	0.014	0.108	0.16
TDS (ppm) (calculated)	395	209	262
Temperature (degrees Celcius)	NA	20.7	NA
Specific Conductance (µS/cm)	NA	189	NA
Turbidity (NTU)	NA	3.7	NA

Notes:
U = not detected
IC = ion chromatography
Silica concentrations were calculated from measured silicon (ICPES).
Bicarbonate concentrations were calculated from measured alkalinity .

groundwater, which results in dilution of the highly soluble salt. The elevated concentration of bromide in the water sample suggests that perched groundwater was not present in the borehole in a significant volume. Elevated concentrations of naturally occurring metals, including aluminum, barium, and iron, most likely result from disaggregation of geologic material during drilling.

Analytical results for the water sample collected from the R-34 surface water tank (GW34-04-53520) are also provided in Table 1-1. This water sample contained 34.4 ppm of bromide, 3.72 ppm of chloride, 0.27 ppm of fluoride, 3.72 ppm of sulfate, and concentrations of nitrate, nitrite, perchlorate, and phosphate that were less than detection.

The groundwater sample (GW34-04-53521) was collected via a submersible pump from the regional aquifer, within the lower Puye Formation, pumiceous subunit. Temperature, turbidity, and pH were determined onsite during sampling. Both filtered (metals, trace elements, and major cations and anions) and nonfiltered (radionuclides, TOC, and stable isotopes) samples were collected. Aliquots of the samples were filtered through a 0.45-micrometer Gelman filter. Samples were acidified with analytical-grade HNO^3 to a pH of 2.0 or less for metal, radionuclide, and major cation analyses. Alkalinity was determined at EES-6 using standard titration techniques.

Results of screening analyses for the groundwater sample (GW34-04-53521) collected from the regional aquifer at R-34 are provided in Tables 1.1 and 1.2. This sample was collected primarily to determine if potential contaminants were present in the regional aquifer. Major potential contaminants of concern at R-34 include mobile solutes such as nitrate, perchlorate, uranium, and tritium. Concentrations of tritium and perchlorate were less than detection and the concentration of nitrate (as N) was less than 0.5 ppm, which is typically observed in supply wells at Los Alamos National Laboratory.

Table 1.2. Hydrochemistry of the Regional Aquifer Sample at Well R-34 (Nonfiltered Samples)

Sample ID Number	**GW34-04-53521**
Depth	**883.7 to 906.6 feet**
Geologic Unit	**Puye Formation (Pumiceous subunit)**
Date Sampled	**09/02/04**
TOC (mgC/L)	1.99
Tritium (pCi/L)	[0.62], U
Am-241 (pCi/L)	[0.0078], U
Cs-137 (pCi/L)	[-0.447], U
Pu-238 (pCi/L)	[0.0047], U
Pu-239,240 (pCi/L)	[0.007], U
Sr-90 (pCi/L)	[0.0765], U
U-234 (pCi/L)	0.445
U-235 (pCi/L)	[0.0187], U
U-238 (pCi/L)	0.211

Notes:
U = not detected
TOC analyzed on 09/01/04.

Appendix B

Borehole Videos

Appendix C

Geophysical Logging Report

Schlumberger Water Services
August 2004

TABLE OF CONTENTS

1.0 SUMMARY

This report describes the borehole geophysical logging measurements acquired in characterization well R-34 by Schlumberger, logged at two separate times in August 2004 – prior to well completion. The report (1) summarizes the technology, measurements, and procedures employed, and (2) presents the processed results from these measurements and discusses their interpretation. The logs were acquired in two trips to the well at two separate times due to borehole conditions preventing logging to the bottom during the first trip. Subsequently, the borehole was reamed and cased off in the top section. The first logging suite was acquired from 31 feet (ft) to 690 ft below ground surface, when the borehole was open (uncased) below 60 ft, drilled with a 12.25-inch (in.) diameter bit size, and contained with a 13.625-in. outer diameter steel casing above 60 ft (as measured by the logs). The second logging suite was acquired from 31 ft to 933 ft below ground surface (bgs), when the borehole was open below 741 ft, drilled with a 12.25-in. diameter bit size, and contained in a 9.625-in. outer diameter freestanding steel casing above 741 ft (as measured by the logs).

The primary purpose of the geophysical logging was to characterize the geologic/hydrogeologic section intersected by the well, with emphasis on determining regional aquifer groundwater level, perched groundwater zones, moisture content, capacity for flow, and the stratigraphy/mineralogy of geologic units. A secondary purpose of the geophysical logging was to evaluate the borehole conditions such as borehole diameter versus depth, deviation versus depth, and degree of drilling fluid invasion. These objectives were accomplished by measuring, nearly continuously, along the length of the well: (1) total and effective water-filled porosity and pore-size distribution from which an estimate of effective water hydraulic conductivity is made (below 741 ft); (2) bulk density (sensitive to total water- plus air-filled porosity); (3) bulk electrical resistivity at multiple depths of investigation (below 741 ft); (4) bulk concentrations of a number of important mineral-forming elements; (5) spectral natural gamma ray, including potassium, thorium, and uranium concentrations; (6) bedding and fracture orientation, fracture aperture, and geologic texture (below 794 ft); (7) borehole inclination and azimuth; and (8) borehole diameter.

Preliminary results of these measurements were generated in the logging truck at the time the geophysical services were performed and are documented in field logs provided onsite. However, the measurements presented in the field results are not fully corrected for borehole conditions and are provided as separate, individual logs. The field results were reprocessed by Schlumberger to (1) correct/improve the measurements, as best as possible, for borehole/formation environmental conditions; (2) perform an integrated analysis of the log measurements so that they are all coherent; and (3) combine the logs in a single presentation, enabling integrated interpretation. The reprocessed log results provide better quantitative property estimates that are consistent for all applicable measurements, as well as estimates of properties that otherwise could not be reliably estimated from the single measurements alone (e.g., total porosity inclusive of all water and air present, water saturation, mineralogy).

The geophysical log measurements from well R-34 provide, overall, good-quality results that are consistent with each other through much of the borehole. The quality of some measurements was degraded across intervals where the borehole contains large washouts, where drilling foam or introduced water was present in the borehole (610 to 690 ft and possibly below 795 ft to some depth), and where the measurement had to be made through casing (690 to 741 ft). The measurements most affected by the adverse borehole conditions were ones that have a shallow depth of investigation and require close contact to the borehole wall—the bulk density, photoelectric effect, and the porosity measurements. The greatest impact on the log processing was erroneously high, estimated air-filled and/or water-filled porosity in the problem zones. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the integrated log analysis results (i.e., the optimized water-filled porosity log) are the most robust single representation of the geophysical log results—providing a wealth of valuable high resolution information on the geologic and hydrogeologic environment of the R-34 locale.

Important results from the processed geophysical logs in R-34 include the following:

1. The well water level was stable throughout the second (deep) logging acquisition, remaining between 794 ft and 795 ft bgs for all four logging runs.

2. The processed logs indicate that the intersected geologic section from 794 ft to the bottom of the log interval (933 ft bgs) is fully saturated with water throughout, possibly representing the top of the regional aquifer. The porosity across this interval is mostly in the range of 25 to 40% of the total rock volume, although it is higher in borehole washouts, which are especially prevalent above 868 ft. The most porous, potentially productive zones in which the logs are not obviously affected by borehole washouts – appear to be 794 to 800 ft, 837 to 842 ft, 846 to 868 ft, 890 to 898 ft, 898 to 901 ft (pumice-rich bed with over 55% porosity), and 901 to 933 ft (bottom of processed log interval). Some of the washed-out zones may also be porous and productive, but they cannot be accurately assessed from the geophysical logs.

3. The processed logs clearly indicate that the clastic, likely fanglomerate, deposits in the interval 756 to 794 ft (directly above the borehole standing water level) are not fully water saturated. The log estimated water saturation in this interval ranges from 35 to 65% water fraction of pore space.

4. The processed log results do indicate possible full-water saturation near the top of the clastic, likely fanglomerate, deposits (710 to 741 ft), as well as in the bottom section of the overlying basalt (647 to 671 ft). However, the log measurements in the apparent saturated clastic zone were made in free-standing casing – possibly affected by water residing in the annulus between the casing and the formation – and the apparently saturated basalt zone containing water/foam in the borehole at the time of logging – possibly artificially saturating the near borehole formation.

5. The basaltic zone intersected by the well from 147 ft to 677 ft (as delineated from the logs) contains both dense, competent zones and large sections of very porous, loose material (possibly cinder) – the latter spanning most of the interval 298 to 611 ft. The processed logs clearly indicate that the loose cinder-like material is unsaturated, while the dense, tight basalts may contain fully water-saturated zones, but the actual water content is very low.

6. The geophysical log response in the zone 134 to 147 ft is characteristic of the Guaje Pumice Bed, with extremely high total porosity (over 60%) and relatively high water-

filled porosity (20 to 32%) that decreases in the upward direction. The logs indicate another possible pumice bed at 340 to 346 ft, with total porosity of over 60% and water-filled porosity of 30%. The pumice bed is overlain by slightly less-porous volcanic tuff (total porosity ranging 40 to 60%).

7. Interpreted bed boundaries across the electrically imaged interval from 794 to 906 ft have dip azimuths (direction to which beds are dipping) predominantly to the southwest and southeast, and have dip angles (angle from horizontal) less than 15 degrees (mostly less than 10 degrees). No fractures were identified across this interval.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well R-34 by Schlumberger in August 2004, prior to initial well completion. The purpose of these services was to acquire in situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This information was (and is) used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging services performed by Schlumberger in well R-34 were the

- Combinable Magnetic Resonance (CMR*) tool to measure the nuclear magnetic resonance response of the formation, which is used to evaluate total and effective water-filled porosity of the shallow formation and to estimate pore size distribution and in-situ hydraulic conductivity;

- Compensated Neutron Tool (CNT*) to measure volumetric water content of the formation, which is used to evaluate moist/porous zones;

- Triple Detector Litho-Density (TLD*) tool to measure formation bulk density and photoelectric factor, which are used to estimate total porosity and lithology;

- Array Induction Tool (AIT*) to measure formation electrical resistivity at five depths of investigation and borehole fluid resistivity, which is used to evaluate drilling fluid invasion into the formation (an indicator of relative permeability and water saturation), presence of moist zones far from the borehole wall, and presence of clay-rich zones;

- Formation Micro-Imager (FMI*) tool to measure electrical conductivity images of the borehole wall in fluid-filled open hole and borehole diameter with a two-axis caliper, used for evaluating geologic bedding and fracturing, including strike and dip of these features and fracture apertures, and rock texture;

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- General Purpose Inclinometry Tool (GPIT*) to measure borehole deviation and azimuth in OH, used to evaluate borehole position versus depth and to orient FMI images;
- Natural Gamma Spectroscopy (NGS) tool to measure gross natural gamma and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, which is used to evaluate geology/lithology, particularly the amount of clay and potassium-bearing minerals;
- Elemental Capture Spectroscopy (ECS*) tool to measure elemental weight percent concentrations of a number of elements, used to characterize mineralogy and lithology of the formation

In addition, calibrated gross gamma ray (GR) was recorded with every service except the NGS for the purpose of depth matching the logging runs to each other. Table 2.1 summarizes the geophysical logging runs performed in R-34.

Table 2.1
Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole R-34

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Tool 3	Depth Interval (ft)
3-Aug-2004	Open hole below 60 ft Bit size of 12.25 in. Steel casing above 60 ft Casing outer diameter (OD) of 13.625 in.	1	TLD	CNT	GR	31 to 692ft
10-Aug-2004	Open hole below 741 ft Bit size of 12.25 in. Free-standing steel casing above 741 ft. Casing OD of 9.625 in.	2	TLD	CNT	GR	664 to 933ft
Same	Same	3	AITH	NGS		31 to 905 ft
Same	Same	8	FMI	GPIT	GR	742 to 918 ft
Same	Same	7	ECS	CMR	GR	71 to 910 ft

A description of these geophysical logging tools can be found on the Schlumberger website (http://www.hub.slb.com/index.cfm?id=id11618).

3.0 METHODOLOGY

This section describes the methods employed by Schlumberger at well R-34 for performed geophysical logging services, including the following stages/tasks:

- Measurement acquisition at the well site
- Quality assessment of logs
- Reprocessing of field data

3.1 Acquisition Procedure

Once the well drilling project team notified Schlumberger that R-34 was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the LANL site, the crew completed site-entry paperwork and received a site-specific safety briefing.

After arriving at the well site, the crew proceeded to rig up the wireline logging system, including

- Parking and stabilizing the logging truck in a position relative to the borehole that is best for performing the surveys;
- Setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig/mast truck);
- Threading the wireline cable through the sheaves; and
- Attaching the appropriate sonde(s) for the first run to the end of the cable.

Next, pre-logging checks and any required calibrations were performed on the logging sondes, and the tool string was lowered into the borehole. If any of the tools required active radioactive sources (in this case a neutron and a gamma source for the CNT/ECS and TLD, respectively) just prior to lowering the tool string, the sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source handling tools. The tool string was lowered to the bottom of the borehole and brought up at the appropriate logging speed as measurements were made. At least two logging runs (one main and one repeat) were made with each tool string.

Upon reaching the surface, any radioactive sources were removed from the tools and returned to their appropriate storage shields, thus eliminating any radiation hazards. Any post-logging measurement checks were performed as part of log quality control and assurance. The tool string was cleaned as it was pulled out of the hole, separated, and disconnected.

The second tool string was attached to the cable for another logging run, followed by subsequent tool strings and logging runs. After the final logging run was completed, the cable and sheave wheels were rigged down.

Before departure, the logging engineer printed field logs for onsite distribution and sent the data via satellite to the Schlumberger data archiving center. The Schlumberger data processing center was alerted that the data were ready for post-acquisition processing.

3.2 Log Quality Control and Assessment

Schlumberger has a thorough set of procedures and protocols for ensuring that the geophysical logging measurements are of very high quality. This includes full calibration of tools when they are first built, regular recalibrations and tool measurement/maintenance checks, and real-time monitoring of log quality as measurements are made. Indeed, one of the primary responsibilities of the logging engineer is to ensure, before and during acquisition, that the log measurements meet prescribed quality criteria.

A tool-specific base calibration that directly relates the tool response to the physical measurement using the designed measurement principle is performed on all Schlumberger logging tools when first assembled in the engineering production centers. This is accomplished through a combination of computer modeling and controlled measurements in calibration models with known physical parameters.

The base calibration for most Schlumberger tools is augmented through regular "master calibrations," typically performed every one to six months in local Schlumberger shops (such as Farmington, NM), depending on tool design. Master calibrations consist of controlled measurements using specially designed calibration tanks/jigs and internal calibration devices that are built into the tools. The measurements are used to fine-tune the tool's calibration parameters and to verify that the measurements are valid.

In addition, on every logging job, onsite before and after "calibrations" are executed for most Schlumberger tools directly before/after lowering/removing the tool string from the borehole. For most tools, these represent a measurement verification instead of an actual calibration – used to confirm the validity of the measurements directly before acquisition and to ensure that they have not drifted or been corrupted during the logging job.

All Schlumberger logging measurements have a number of associated depth-dependent quality control (QC) logs and flags to assist with identifying and determining the magnitude of log quality problems. These QC logs are monitored in real-time by the logging engineer during acquisition and are used in the post-acquisition processing of the logs to determine the best processing approach for optimizing the overall validity of the property estimates derived from the logs.

Additional information on specific tool calibration procedures can be found on the Schlumberger web page (http://www.hub.slb.com/index.cfm?id=id11618).

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data archived, the data were downloaded to the Schlumberger processing center. There the data were processed in the following sequence, to (1) correct the measurements for near-wellbore environmental conditions and redo the raw measurement field processing for certain tools using better processing algorithms, (2) depth match and splice the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Separately, the FMI electrical image was processed to produce scaled and normalized high-resolution images that were interpreted to identify geologic features and compute fracture apertures. Afterwards, an integrated log montage was built to combine and compile all the processed log results.

3.3.1 Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (water or air), presence of steel casing, and (to a much lesser extent) pressure, temperature, and fluid salinity. Basically, these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In R-34, the log measurements requiring these corrections are the CNT porosity, TLD density, ECS elemental concentrations, and NGS spectral gamma ray logs.

Two CNT neutron porosity measurements are available – one that measures thermal ("slow") neutrons and one that measures epithermal ("fast") neutrons. Measurement of epithermal neutrons is required to make neutron porosity measurements in air-filled holes. In water/mud-filled holes both the CNT epithermal and thermal neutron measurements are valid, but the thermal neutron porosity has better statistical precision. The neutron logging response, thermal and epithermal, to drilling foam in the borehole (used for drilling of R-34 and other LANL wells) is somewhere between water and air and, thus, difficult to characterize and correct for. Both epithermal and thermal neutron porosity measurements were made in R-34 since the borehole was partly water-filled (below 650 ft during the first logging and 825 ft during the second logging), partly air-filled (above 610 ft during the first logging and 727 ft during the second logging), with variably wet foam in between the air-filled and water-filled sections. Epithermal neutron porosity was processed at the field site for borehole fluid type (air versus water) and other environmental conditions and didn't require any further processing. The thermal neutron porosity measurement was reprocessed for borehole conditions, although the results were very similar to the field logs. For further processing and analysis (e.g., ELAN analysis), the reprocessed thermal neutron porosity log was used. Both the thermal and epithermal neutron porosity measurements cannot be properly corrected in the foam-filled section of the borehole.

The standard open-hole processing algorithm used for the TLD density measurement is influenced by the steel density in a cased hole. A cased-hole density algorithm was applied to the raw TLD field measurements obtained in cased hole sections of the combined, separately acquired log intervals (comprising 37 to 60 ft and 689 to 741 ft) to try to eliminate the casing response. While the algorithm can account for the casing per se, it cannot account for air- or water-filled gaps in the annulus between the casing and the formation that cause erroneously low-bulk density readings.

The raw ECS elemental yield measurements include the contribution of iron from steel casing and hydrogen from fluid in the borehole. The processing consists of subtracting these unwanted contributions from the raw normalized yields, then performing the normal elemental yields-to-weight fraction processing. The contribution to subtract is a constant baseline amount (or zoned constant values if there are bit/casing size changes), usually determined by comparing the normalized raw yields in zones directly below/above the borehole fluid/casing change. Casing corrections were applied to the ECS logs – only acquired during the second logging in R-34 – across the interval from 71 to 741 ft. At the time of the second logging the borehole water level was 794 ft; no hydrogen correction was required in the air-filled section above 794 ft and the difference between the hydrogen yield above and below this depth was used to determine the baseline borehole hydrogen correction to apply below.

The NGS spectral gamma ray are affected by the material (fluid, air, casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the NGS measures incoming gamma rays emitted by radioactive elements in the formation surrounding the borehole. The processing algorithms try to correct for the damping influence of the borehole material. The NGS logs from R-34 were reprocessed to fully account for the environmental effects of the borehole fluid (water and air), hole size, and casing (the latter above 741 ft). The second string of casing above 60 ft was not corrected for.

The measurements cannot be fully corrected for borehole washouts or rugosity, as well as the annulus material (e.g., bentonite grout) between casing and the formation, since the specific characteristics of these features (e.g., geometry) are unknown and their effects on the measurements are often too significant to account for. Thus, the compromising effects of these conditions on the measurements should be accounted for in the interpretation of the log results.

3.3.2 Depth-Matching and Splicing

Once the logs were environmentally corrected for the conditions in the borehole and the raw measurement reprocessing was completed, the logs from different tool runs were depth-matched to each other using the AIT-NGS tool run as the base reference. Gamma ray was used as the common correlation log measurement for depth-matching the different runs. The second logging suite (August 3, 2004) was depth-matched to the first suite (August 10, 2004) by shifting the AIT-NGS tool run logs from the second suite to the AIT-NGS run from the first suite (using gross gamma), then depth-matching the logs from the remaining second suite tool runs to the depth-shifted AIT-NGS run (using gross gamma). Once all the logs were on depth with each other, logs from the August 10 logging runs (spanning the bottom approximately 200 ft of R-34) were spliced to the equivalent logs from the August 3 logging runs (spanning the top approximately 700 ft of R-34).

3.3.3 Integrated Log Analysis

An integrated log analysis, using as many of the processed logs as possible, was performed to model the near-wellbore substrate lithology/mineralogy and pore fluids. This analysis was performed using the Elemental Log Analysis (ELAN*) program (Mayer and Sibbit, 1980; Quieren et al, 1986) – a petrophysical interpretation program designed for depth-by-depth quantitative formation evaluation from borehole geophysical logs. ELAN estimates that the volumetric fractions of user-defined rock matrix and pore constituents at each depth based on the known log measurement responses to each individual constituent by itself[1]. ELAN requires an a priori specification of the volume components present within the formation—fluids, minerals, and rocks. For each component, the relevant response parameters for each measurement are also required. For example, if one assumes that quartz is a volume component within the formation and the bulk density tool is used, then the bulk density parameter for this mineral is well known to be 2.65 grams/cubic centimeter (g/cc).

The logging tool measurements, volume components, and measurement response parameters used in the ELAN analysis for R-34 are provided in Table 3.1. The final results of the analysis – an optimized mineral-fluid volume model – are shown on the integrated log montage, 3rd track from the right (inclusive of the depth track). To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (71 to 933 ft), as many as

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[1]Mathematically, this corresponds to an inverse problem – solving for constituent volume fractions from an (over)determined system of equations relating the measured log results to combinations of the tool measurement response to individual constituents.

Table 3.1
Tool measurements, volumes, and respective parameters used in the R-34 ELAN analysis

Volume / Tool Measurement	Air	Capillary-Bound Water	Water	Hornblende	Hypersthene	Labradorite	Silica Glass	Heavy Mafic Minerals	Augite	Montmorillinite	Pyrite	Orthoclase/ Sanidine	Calcite	Quartz
Bulk density (g/cc)	–0.16	1.00	1.00	3.11	3.55	2.65	2.33	4.0	3.08	2.1	4.99	2.58 2.56		2.64
Epithermal neutron porosity (ft^3/ft^3)	0	1.00	1.00	0.05	0.01	-0.01	0.0	0.02	-0.01	0.6	0.17	-0.01	0.0	-0.047
Thermal neutron porosity (ft^3/ft^3)	0	1.00	1.00	0.06	0.04	-0.01	-0.03	0.07	0.02	0.65	0.01	-0.01	0.0	-0.02
Volumetric photoelectric effect	0	0	0.40	12	20.2	7	4.2	65	23.8	4.4	82.1	7.3 7.0	14.1	4.8
Total CMR water-filled porosity (ft^3/ft^3)	0	1.0	1.0	0	0	0	0	0	0	0.425	0	0	0	0
CMR bound fluid volume (ft^3/ft^3)	0	1.0	0	0	0	0	0	0	0	0.425	0	0	0	0
Resistivity (ohm-m)	Very high	35	35	Very high	Very high	Very high	Very high	Very high	Very high	1.5	Very high	Very high	Very high	Very high
Dry weight silicon (lbf / lbf)	0.0	0.0	0.0	0.21	0.24	0.24	0.47	0.18	0.23	0.26	0	0.3 0.38	0	0.47
Dry weight calcium (lbf / lbf)	0.0	0.0	0.0	0.09	0.0	0.09	0.0	0.0	0.10	0.01	0.0	0.0	0.405	0.0
Dry weight iron (lbf / lbf)	0.0	0.0	0.0	0.08	0.20	0.02	0.0	0.22	0.11	0.04	0.47	0.02	0.0	0.0
Dry weight sulfur (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.0	0.0	0.0
Dry weight titanium (lbf / lbf)	0.0	0.0	0.0	0.005	0.01	0.0	0.0	0.0	0.048	0.0	0.0	0.0	0.0	0.0
Dry weight aluminum (lbf / lbf)	0.0	0.0	0.0	0.07	0.0	0.16	0.0	0.0	0.02	0.11	0.0	0.10	0.0	0.0
Wet weight potassium (lbf / lbf)	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.003	0.005	0.0	0.102	0.0	0.0
Weight hydrogen (lbf / lbf)	0.0	0.111	0.111	0.0	0.0	0.0	0.01	0.0	0.0	0.025	0.0	0.0	0.0	0.0
Wet weight thorium (ppm)	0.0	0.0	0.0	50	25	3	2	4	20	24	0	5.5	0.0	2
Clay bound water volume (ft^3/ft^3)	0	0	0	0	0	0	0	0	0	0.425	0	0		0
Magnetic Field Variation (mT)	0	0	0	0	0	0	0	2	0	0	0.5	0		0

possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Not all the tool measurements shown in Table 3.1 are used for the entire interval analyzed, as not all the measurements are available, or of good quality, across certain sections of the borehole. To accommodate fewer tool measurements certain model constituents are removed from the analysis in some intervals. Most notably, below 910 ft many of the minerals had to be removed from the model due to the absence of many of the logs.

The ELAN analysis was performed with as few constraints or prior assumptions as possible. A considerable effort was made to choose a set of minerals or mineral types for the model that is representative of Los Alamos area geology and it's volcanic origins. No prior assumption is made about water saturation—where the boundary between saturated and unsaturated zones lies (e.g., the depth to the top of the regional aquifer or perched zones). Thus, the presence and amount of air in the pore space is unconstrained. Total porosity and water-filled porosity are also left unconstrained throughout the analysis interval. Thus, interpretations should be made from the ELAN results with the understanding that the mineral-fluid model represents a mathematically optimized solution that is not necessarily a physically accurate representation of the native geologic formation. Within this context, the ELAN model is a robust estimate of the bulk mineral-fluid composition that accounts for the combined response from all the geophysical measurements.

4.0 RESULTS

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in R-34 were generated in the logging truck at the time the geophysical services were performed and were documented in the field logs provided onsite. However, the measurements presented in the field results are not fully corrected for undesirable (from a measurement standpoint) borehole and geologic conditions and are provided as separate, individual logs. The field log results have been processed (1) to correct/improve the measurements, as best as possible, for borehole/formation environmental conditions; and (2) to depth-match the logs from different tool runs in the well and splice the top (August 3, 2004) and bottom (August 10, 2004) logging suites. Additional logs were generated from integrated analysis of processed measured logs, providing valuable estimates of key geologic and hydrologic properties.

The processed log results are presented as continuous curves of the processed measurement versus depth and are displayed as (1) a one-page, compressed summary log displays for selected directly related sets of measurements (see Figures 4.1, 4.2, and 4.3); and (2) an integrated log montage that contains all the key processed log curves, on depth and side by side. The summary log displays address specific characterization needs, such as moisture content, water saturation, and lithologic changes. The purpose of the integrated log montage is to present, side by side, all the most salient reprocessed logs and log-derived models, depth-matched to each other, so that correlations and relationships between the logs can be identified.

Important results from the processed geophysical logs in R-34 are described below.

4.1 Well Water Level

The standing water level in R-34 was steady at 794 to 795 ft bgs during the August 10, 2004, logging. During the earlier August 3 logging, a mixture of foam and water – likely derived primarily from the drilling process – was present at the bottom of the log interval below 650 ft.

4.2 Regional Aquifer

The processed geophysical logs indicate a significant increase in water saturation below 794 ft, to which is coincident with the well water level at the time of the logging. The estimated pore-volume water saturation (fraction of the total pore volume containing water) computed from the ELAN analysis is high (above 75%) from 794 ft to the bottom of the log interval (933 ft), compared with 40 to 65% in the interval directly above 794 ft. The estimate is even higher when computed directly from bulk density and ELAN water-filled porosity for a grain density range of 2.45 g/cc to 2.65 g/cc – ranging from 80% (2.65 g/cc) to consistently 90 to 100% (2.45 g/cc). These results suggest that the regional aquifer groundwater level may reside at 794 ft in this location, with the Regional Aquifer itself below. However, if the borehole water level is higher than the ground water level in the surrounding geologic formation (e.g., due to confined conditions in the aquifer), the logging measurements could be reading higher water content, and thus water saturation, than actually exists – due to induced saturation of the near-borehole formation, which is the volume to which most of the porosity logs are sensitive.

Water-filled and total porosity[2] mostly ranges from 25 to 40% across the bottom of the log interval that intersects the apparent Regional Aquifer (794 to 933 ft), although there are a number of zones with elevated porosity – mostly associated with borehole washouts. Key hydrogeologic characteristics observed from the logs across this interval are described below (referenced to depth below ground surface):

- **794 to 800 ft**: Moderately washed-out zone characterized by very high total and water-filled porosity (43%), as well as effective porosity (30 to 35%), except water-filled and effective porosity drops to 30% and 18%, respectively, at 799 ft (where the borehole is more gauge). The very high log-measured porosity values in the top section could be elevated due to the washed-out, rugose borehole condition. The FMI and ELAN results indicate that the interval does not contain much clay and other fine-grained material – suggestive of productive aquifer material.
- **800 to 807 ft**: Severely washed-out zone characterized by unrealistically high total and water-filled porosity (as high as 80% of total rock volume), as well as effective porosity (as high as 65%). The log-measured porosity values are obviously adversely affected by the washouts – making it very difficult to determine the true formation porosity and water content from the logs in this zone.
- **807 to 817 ft**: This zone has much lower total and water-filled porosity (25 to 50%) than the surrounding severely washed-out zones. Estimated effective porosity is also much lower – 10 to 25% – except for a sharp peak of 40% at 814 ft (likely associated with an

[2] Water-filled porosity is defined in this report as the fraction of the total rock volume occupied by water. Total porosity is defined as fraction of the total rock volume occupied by water plus air, plus any other fluid or gas (non-solid).

abrupt washout). The FMI and ELAN results indicate that the interval contains some clay and other fine-grained material – suggestive of less-productive aquifer material.

- **817 to 828 ft**: Severely washed-out zone characterized by unrealistically high total and water-filled porosity (as high as 80% of total rock volume), as well as effective porosity (as high as 65%). The log-measured porosity values are obviously adversely affected by the washouts – making it very difficult to determine the true formation porosity and water content from the logs in this zone.
- **828 to 834 ft**: This zone has much lower water-filled and effective porosity (25 to 30% and 0 to 17%, respectively) than the surrounding severely washed-out zones. Total porosity is continuously about 5% higher than water-filled porosity, resulting in a water saturation estimate of 70 to 80% of pore volume. However, the uncertainty in the water saturation estimate is quite high, especially at the lower porosity values measured in this interval. Within this uncertainly, it is quite possible (and probably likely based on the results from the surrounding zones) that the true water saturation is 100% (fully water saturated). The FMI and ELAN results indicate that the interval contains some clay and other fine-grained material – suggestive of less-productive aquifer material.
- **834 to 837 ft**: Severely washed-out zone characterized by unrealistically high total and water-filled porosity (65% and 52%, respectively), as well as effective porosity (45%). The log-measured porosity values are obviously adversely affected by the washout – making it very difficult to determine the true formation porosity and water content from the logs in this zone.
- **837 to 842 ft**: This zone has lower total and water-filled porosity (30 to 35%) than the surrounding severely washed-out zones, but has realistically high effective porosity (20 to 30%). The FMI and ELAN results indicate that the interval does not contain much clay and other fine-grained material – suggestive of productive aquifer material.
- **842 to 846 ft**: Severely washed-out zone characterized by unrealistically high total and water-filled porosity (as high as 70% and 60%, respectively), as well as effective porosity (as high as 55%). The log-measured porosity values are obviously adversely affected by the washout – making it very difficult to determine the true formation porosity and water content from the logs in this zone.
- **846 to 868 ft**: This variably washed-out zone has total and water-filled porosity ranging 27 to 48% and 30 to 55%, respectively. Effective porosity varies from about 10% to 35%. Zones with the highest effective porosity are 848 to 856 ft (20 to 32%, although this could be elevated due to washouts), 860 to 864 ft (20 to 35%, but also is opposite of a washout), and 866.5 to 868 ft (27%, but opposite of a washout). The FMI and ELAN results indicate that these zones do not contain much clay and other fine-grained material – suggestive of productive aquifer material.
- **868 to 890 ft**: This interval is much less washed out than most of the zones above. Water-filled porosity trends lower from top (39%) to bottom (23%), with total porosity continuously about 3% higher. Estimated effective porosity is generally lower than surrounding intervals (ranging 12 to 22%), which corresponds well with the presence of clay and other fine-grained material indicated by the FMI and ELAN.

- **<u>890 to 898 ft</u>**: This interval has a water-filled porosity of 30%, much of which is estimated to be effective porosity (20 to 30%). The FMI and ELAN results indicate that the interval does not contain much clay and other fine-grained material -- also suggestive of productive aquifer material.
- **<u>898 to 901 ft</u>**: This zone has a very high water-filled porosity (58%), but is not washed out. Effective porosity is estimated to be almost as high, although this depth is below the bottom of the CMR log (the primary tool used to measure effective porosity). The FMI image suggests that this zone corresponds to a thin, highly porous pumice bed – likely very productive aquifer material.
- **<u>901 to 933 ft</u>** (bottom of log interval): Hole conditions are good across this interval. Water-filled porosity is quite consistent – ranging from 23 to 26%. A valid estimate of effective porosity could not be obtained in this interval. The FMI indicates a thin clay-rich zone immediately below the pumice bed, underlain by clean (non-clay) material to the bottom of the FMI log (906 ft).

4.3 Vadose Zone Perched Water

The processed logs indicate a highly variable total and water-filled porosity, and, thus, water saturation, above 794 ft (the apparent regional aquifer groundwater level), but the water-filled porosity is generally lower than it is below 794 ft. Key hydrogeologic characteristics observed from the logs across the log interval from 71 to 794 ft are described below, from bottom to top (referenced to depth below ground surface):

- **<u>756 to 794 ft</u>**: Water saturation varies between 35% and 65% – much lower than the log interval below 794 ft. Water-filled porosity stays consistent at 17 to 20% and total porosity ranges 28 to 40%. Estimated effective porosity remains at 10% or less.
- **<u>740 to 756 ft</u>**: This section of the borehole was severely washed out during the logging, likely adversely impacting the porosity log measurements. Estimated water saturation is highly variable (10 to 100%) due to highly variable measured porosity (10 to 40% water-filled porosity and 17 to 60% total porosity). No valid measurement of effective porosity could be ascertained across this interval and all above depths, due to the effect of the overlying steel casing (casing bottom at 740 ft) on the CMR measurement.
- **<u>690 to 740 ft</u>**: The porosity log measurements were acquired in freestanding casing across this section of the borehole. The estimated water saturation is high – 100% below 710 ft, decreasing to 70% at 690 ft. The measured total porosity is relatively low (20 to 30%), with water-filled porosity consistent at 20%. It is possible that water was present in the annulus between the casing and the formation, resulting in an elevated water-filled porosity log measurement.
- **<u>675 to 690 ft</u>**: This section of the borehole was severely washed out during the logging, resulting in some unrealistically high porosity log measurements (20 to 53% water-filled porosity and 32 to 80% total porosity). Estimated water saturation varies from 55% to 85%.
- **<u>647 to 675 ft</u>**: Porosity logs across this interval were obtained when the borehole was open (first logging) and contained minimal washouts. Interestingly, the porosity logs indicate fully water-saturated near borehole conditions at the time of logging. The

estimated water-filled and total porosity is consistently close to 40%. This section of the borehole was filled with water-laden drilling foam at the time of logging and it is possible the borehole liquid artificially saturated the surrounding formation – as measured by the porosity logs.

- **622 to 647 ft**: The processed logs across this interval are characterized by relatively low, highly variable porosity (10 to 30% total porosity). Water-filled porosity, and thus water saturation, is largely undeterminable due to the lack of valid moisture logs.
- **610 to 622 ft**: This interval is characterized by relatively high, variable porosity (20 to 50% total porosity). Water-filled porosity, and thus water saturation, is largely undeterminable due to the lack of valid moisture logs.
- **576 to 610 ft**: The processed logs across this severely washed out interval show very high total porosity (37 to 60%) and moderate (15 to 30%) water-filled porosity, with an anomalous peak of 60% at 608 ft. Estimated water saturation varies mostly from 35 to 58%, except that it reaches 100% at the 608-ft anomaly.
- **532 to 576 ft**: The processed logs across this severely washed-out interval indicate extremely high total porosity (48 to 65% total porosity), low water-filled porosity (10 to 20%), and, thus, low water saturation (15 to 37%).
- **522 to 532 ft**: The processed logs suggest that this zone is extremely dense, resulting in a very low total porosity estimate (0 to 10%) and 100% water saturation – likely caused more by an erroneous bulk density log measurement than an actual geologic property change.
- **477 to 522 ft**: This interval is also severely washed out, and the processed logs indicate very high total porosity (45 to 65%) and low water-filled porosity (5 to 28%), resulting in a low water saturation estimate (5 to 42%).
- **475 to 477 ft**: The log response in this zone is dominated by a high bulk density log anomaly, resulting in a very low total porosity estimate (20%), which, combined with a water-filled porosity of 10 to 18%, yields a higher water saturation (65%) than the surrounding high porosity interval.
- **456 to 475 ft**: This section is similar to log response across most of this section of the borehole, the processed logs are characterized by very high total porosity (48 to 67%) and low water-filled porosity (3 to 28%), leading to a low water saturation estimate (5 to 50%).
- **446 to 456 ft**: The processed logs indicate another anomalous extremely dense zone here, resulting in a very low total and water-filled porosity estimate (5 to 10%) and 100% water saturation – likely caused more by an erroneous bulk density log measurement than an actual geologic property change.
- **380 to 446 ft**: This section is similar to log response across most of this section of the borehole – high total porosity (48 to 65%) and low water-filled porosity (3 to 18%), leading to a low water saturation estimate (10 to 35%).
- **370 to 380 ft**: Another high-bulk-density log anomaly occurs in this zone – resulting in an extremely low total and water-filled porosity estimate (0 to 3%) and 100% water

saturation. The anomalous log results are likely caused more by an erroneous bulk density log measurement than an actual geologic property change.

- **322 to 370 ft**: The processed logs across this severely washed-out interval indicate very high total porosity (40 to 65%) and low water-filled porosity (12 to 15%), yielding a low water saturation estimate (15 to 30%).
- **310 to 322 ft**: The processed log results across this interval show low total porosity (20 to 23%), higher water-filled porosity (18 to 19%) than the interval below, and high water saturation (72 to 88%). Hole conditions were very good so the log response is of good quality, but this section of the borehole was cemented prior to redrilling and logging. Thus, the log measurements may be responding significantly to the emplaced cement.
- **296 to 310 ft**: This interval again contains severe washouts, and the processed log results indicate a very high total porosity (58 to 65%) and mostly low water-filled porosity (5 to 20%) and, thus, water saturation (8 to 30%) – except for a high water-filled porosity (45%) and 100% water saturation at the bottom of the interval (309 ft).
- **147 to 296 ft**: The processed log results from this long interval predominantly portray very low total porosity (mostly less than 10%) that is water-filled (100% water saturation). However, there are a number of zones with significantly higher total porosity (as high as 60%, but mostly 20 to 40%), slightly elevated water-filled porosity, and much lower water saturation (mostly less than 60%): 288 to 290 ft, 278 to 280 ft, 272 to 276 ft, 256 to 270 ft, 229 to 236 ft, 239 to 226 ft, 215 to 224 ft, 208 to 214 ft, 190 to 197 ft, 182 to 188 ft, and 162 to 166 ft. It is possible that the higher porosity is an artifact of borehole washouts and their effect on the bulk density measurement.
- **134 to 147 ft**: The processed log results are characterized by extremely high total porosity (63%), with higher water content than surrounding intervals (20 to 25%, with a peak of 32% at very bottom – directly overlying the low porosity basalt). Estimated water saturation varies from 28% to 52% at the bottom. Borehole conditions look reasonable, suggesting the porosity measurements are of good quality. The log response is characteristic of the Guaje Pumice Bed, as seen in many other Los Alamos wells.
- **108 to 134 ft**: The processed logs indicate very high, consistent total porosity (48%) and water-filled porosity that decreases from 20% at the bottom to 13% at the top. The total porosity is noticeably less than the surrounding intervals.
- **104 to 108 ft**: This zone is characterized by extremely high total porosity (60%) and low water-filled porosity (5 to 15%) from the processed logs.
- **102 to 104 ft**: There is an anomalously high bulk density response in this zone, resulting in a very low total porosity estimate (4%), matching water-filled porosity and, thus, 100% water saturation from the processed logs. The anomalous results are likely caused more by an erroneous bulk density log measurement than an actual geologic property change.
- **71 to 102 ft (top of processed log interval)**: The top of the processed log interval is characterized by a continuation of extremely high total porosity (50 to 61%) and low water-filled porosity (10 to 20%, with the highest amounts at bottom). Water-filled porosity is higher than the zone directly below – possibly suggesting that water is collecting on top of a thin, low porosity bed (see description above of underlying zone).

4.4 Geology

The processed geophysical log results clearly delineate the geologic material and formation contacts intersected by R-34. The generalized geologic stratigraphy observed from the logs across the logged interval is as follows (depth below ground surface):

- **71 to 102 ft (top of processed log interval): Very porous volcanic tuff** to characterized by very high total porosity (50 to 61% of total rock volume), high sanidine and silica mineral/glass content, and moderate amounts of augite or similar minerals

- **102 to 104 ft: Very low-porosity, dense volcanic tuff (likely bulk density log anomaly)** – characterized by very low total porosity (7% of total rock volume) – derived from a suspect bulk density log anomaly – high sanidine and silica mineral/glass content

- **104 to 108 ft: Very porous volcanic tuff** – characterized by very high total porosity (48% of total rock volume), high sanidine and silica mineral/glass content, and moderate amounts of augite or similar minerals

- **108 to 134 ft: Porous volcanic tuff** – characterized by high total porosity (40 to 50% of total rock volume), high sanidine and silica mineral/glass content, and moderate amounts of augite or similar minerals

- **134 to 147 ft: Extremely porous volcanic pumice bed** – characterized by extremely high total porosity (63% of total rock volume), and high sanidine and silica glass content, moderate amounts of augite or similar minerals, and minor amounts of calcite or other calcium-bearing minerals. The log response is characteristic of the Guaje Pumice Bed, as seen in many other Los Alamos wells.

- **147 to 296 ft: Basalt lava, predominantly dense and competent with some possible rubble zones** – characterized by very low total porosity (mostly 5 to 10% of total rock volume), with some possible high porosity rubble zones at 163 to 166 ft, 182 to 187 ft, 190 to 196 ft, 208 to 214 ft, 216 to 222 ft, 230 to 236 ft, and 257 to 266 ft (some or all of which could be bulk density log measurement artifacts resulting from borehole washouts); variably high plagioclase or quartz content; moderate augite content; and relatively minor amounts of heavy mafic minerals

- **296 to 310 ft: Extremely porous basaltic material, likely cinders (scoria)** – characterized by extremely high total porosity (62% of total rock volume), variably high plagioclase or quartz content, moderate augite content, and relatively high heavy mafic mineral content

- **310 to 322 ft: Calcium-rich basalt lava, relatively low porosity and competent** – characterized by relatively low total porosity (mostly 21% of total rock volume), high plagioclase content, and relatively minor amounts of potassium feldspar and quartz/silica glass

- **322 to 370 ft: Extremely porous basaltic material, likely cinders (scoria)** – characterized by extremely high total porosity (40 to 62% of total rock volume), high plagioclase content, moderate augite content, highly variable quartz content, and small amounts of heavy mafic minerals

- 370 to 380 ft: **Very low-porosity, dense basalt lava (likely bulk density log anomaly)** – characterized by very low total porosity (0 to 2% of total rock volume) – derived from a suspect bulk density log anomaly – variably high plagioclase or quartz content, moderate augite content, and minor amounts of hypersthene or similar minerals
- 380 to 446 ft: **Extremely porous basaltic material, likely cinders (scoria)** – characterized by extremely high total porosity (50 to 63% of total rock volume), variably high plagioclase or quartz (mostly quartz) content, moderate augite and potassium feldspar content, and relatively high heavy mafic mineral content
- 446 to 456 ft: **Very low porosity, dense basalt lava (likely bulk density log anomaly)** – characterized by very low total porosity (5 to 10% of total rock volume) – derived from a suspect bulk density log anomaly – variably high plagioclase or quartz content, and moderate augite content
- 456 to 475 ft: **Extremely porous basaltic material, likely cinders (scoria)** – characterized by extremely high total porosity (50 to 65% of total rock volume), variably high plagioclase or quartz content, moderate augite and potassium feldspar content, and highly variable heavy mafic mineral content
- 475 to 477 ft: **Low porosity, dense basalt lava (possible bulk density log anomaly)** to characterized by low total porosity (20% of total rock volume) – derived from a suspect bulk density log anomaly – variably high plagioclase or quartz content, and moderate augite, potassium feldspar, and heavy mafic mineral content
- 477 to 522 ft: **Extremely porous basaltic material, likely cinders (scoria)** – characterized by extremely high total porosity (47 to 65% of total rock volume), variably high plagioclase or quartz content, moderate augite and potassium feldspar content, and relatively high and variable heavy mafic mineral content
- 522 to 532 ft: **Very low porosity, dense basalt lava (likely bulk density log anomaly)** – characterized by very low total porosity (0 to 10% of total rock volume) – derived from a suspect bulk density log anomaly – variably high plagioclase or quartz content, moderate augite and potassium feldspar content, and relatively high and variable heavy mafic mineral content
- 532 to 576 ft: **Extremely porous basaltic material, likely cinders (scoria)** – characterized by extremely high total porosity (42 to 67% of total rock volume), variably high plagioclase or quartz (mostly quartz) content, moderate augite and potassium feldspar content, and relatively high and variable heavy mafic mineral content
- 576 to 610 ft: **Very porous basaltic material, likely cinders (scoria)** – characterized by very high total porosity (37 to 57% of total rock volume), variably high plagioclase or quartz (mostly quartz) content, moderate augite and potassium feldspar content, and relatively high and variable heavy mafic mineral content
- 610 to 647 ft: **Basalt lava, variably competent with rubble zones** – characterized by highly variable total porosity (7 to 45% of total rock volume), variably high plagioclase

or quartz content, moderate augite content, and relatively low potassium feldspar and heavy mafic mineral content

- <u>647 to 677 ft</u>: **Porous basalt lava** – characterized by high, mostly consistent total porosity (mostly 32 to 43% of total rock volume) – except for a very high porosity peak at 645 ft – high plagioclase content, moderate quartz and augite content, and relatively low potassium feldspar and heavy mafic mineral content

- <u>677 to 727 ft</u>: **Fanglomerate** – characterized by moderate-to-low total porosity (20 to 40% of total rock volume, decreasing from top to bottom), high silica mineral/glass and potassium feldspar content, moderate-to-low (but consistent) augite content, low and highly variable plagioclase content, and minor amounts of heavy mafic minerals

- <u>727 to 755 ft</u>: **Fanglomerate** – characterized by high total porosity (25 to 63% of total rock volume – highest values likely caused by effect of washouts on porosity logs); high silica mineral/glass and potassium feldspar content; moderate-to-low, highly variable augite, plagioclase, and hypersthene content; highly variable, minor amounts of heavy mafic minerals

- <u>755 to 794 ft</u>: **Heterogeneous fanglomerate containing clay** – characterized by moderate, fairly consistent total porosity (25% to 40%, highest at the bottom); high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and the presence of varying, relatively small amounts clay

- <u>794 to 805 ft</u>: **Heterogeneous fanglomerate** – characterized by highly variable, very high total porosity (50 to 80%) – the measurements obviously were affected by severe washouts; high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and no evidence of clays

- <u>805 to 817 ft</u>: **Heterogeneous fanglomerate-containing clay** – characterized by much lower total porosity (25 to 50%) than the surrounding severely washed-out zones; high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and the presence of varying, relatively small amounts clay

- <u>817 to 828 ft</u>: **Heterogeneous fanglomerate** – characterized by highly variable, very high total porosity (42 to 80%) – the measurements obviously affected by severe washouts; high potassium feldspar and silica mineral/glass content; low plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and no evidence of clays

- <u>828 to 834 ft</u>: **Heterogeneous fanglomerate containing clays** – characterized by much lower total porosity (25 to 30%) than the surrounding severely washed-out zones; high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and the presence of varying, relatively small amounts clay

- **834 to 846 ft: Heterogeneous fanglomerate** – characterized by highly variable, generally very high total porosity (35 to 70%) – the measurements obviously affected by severe washouts; high potassium feldspar and silica mineral/glass content; moderate, highly variable plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and no evidence of clays
- **846 to 868 ft: Heterogeneous fanglomerate** – characterized by high total porosity (32 to 58%, highest values likely caused by the effect of washouts on porosity logs); high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and only variable, minor amounts of clay
- **868 to 890 ft: Heterogeneous fanglomerate containing clay** – characterized by consistent, relatively high total porosity (30 to 42%, generally decreasing towards the bottom); high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and the presence of relatively significant amounts of clay
- **890 to 898 ft: Heterogeneous fanglomerate** – characterized by moderate total porosity (32 to 42%, highest values at bottom); high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and only variable, minor amounts of clay
- **898–901 ft: Extremely porous pumice bed** – characterized by very high total porosity (58% in an interval that is not washed out); high potassium feldspar and silica mineral/glass content; moderate plagioclase content; small amounts of augite, hypersthene, hornblende, and/or heavy mafic minerals; and only minor amounts of clay
- **901 to 933 ft (bottom of log interval): Porous fanglomerate** – characterized by consistent, high total porosity (31–40%), and high silica mineral/glass content (other minerals undeterminable due to lack of available logs)

4.5 Summary Logs

Three summary log displays have been generated for R-34 to highlight the key hydrogeologic and geologic information provided by the processed geophysical log results:

- Porosity summary log showing continuous hydrogeologic property logs, including total and moveable water content and water saturation – highlights hydrologic information obtained from the integrated log results (Figure 4.1)
- Density and clay content summary showing a continuous logs of formation bulk density and estimated grain density, as well as photoelectric factor (sensitive to mineralogy) and estimated clay volume – highlights key geologic rock matrix information obtained from the log results (Figure 4.2)
- Spectral natural gamma ray and lithology summary showing a high vertical resolution, continuous volumetric analysis of formation mineral and pore fluid composition (based on an integrated analysis of the logs) and key lithologic/stratigraphic correlation logs from the spectral gamma ray measurement (concentrations of gamma-emitting elements) – highlights the geologic lithology, stratigraphy and correlation information obtained from the log results (Figure 4.3).

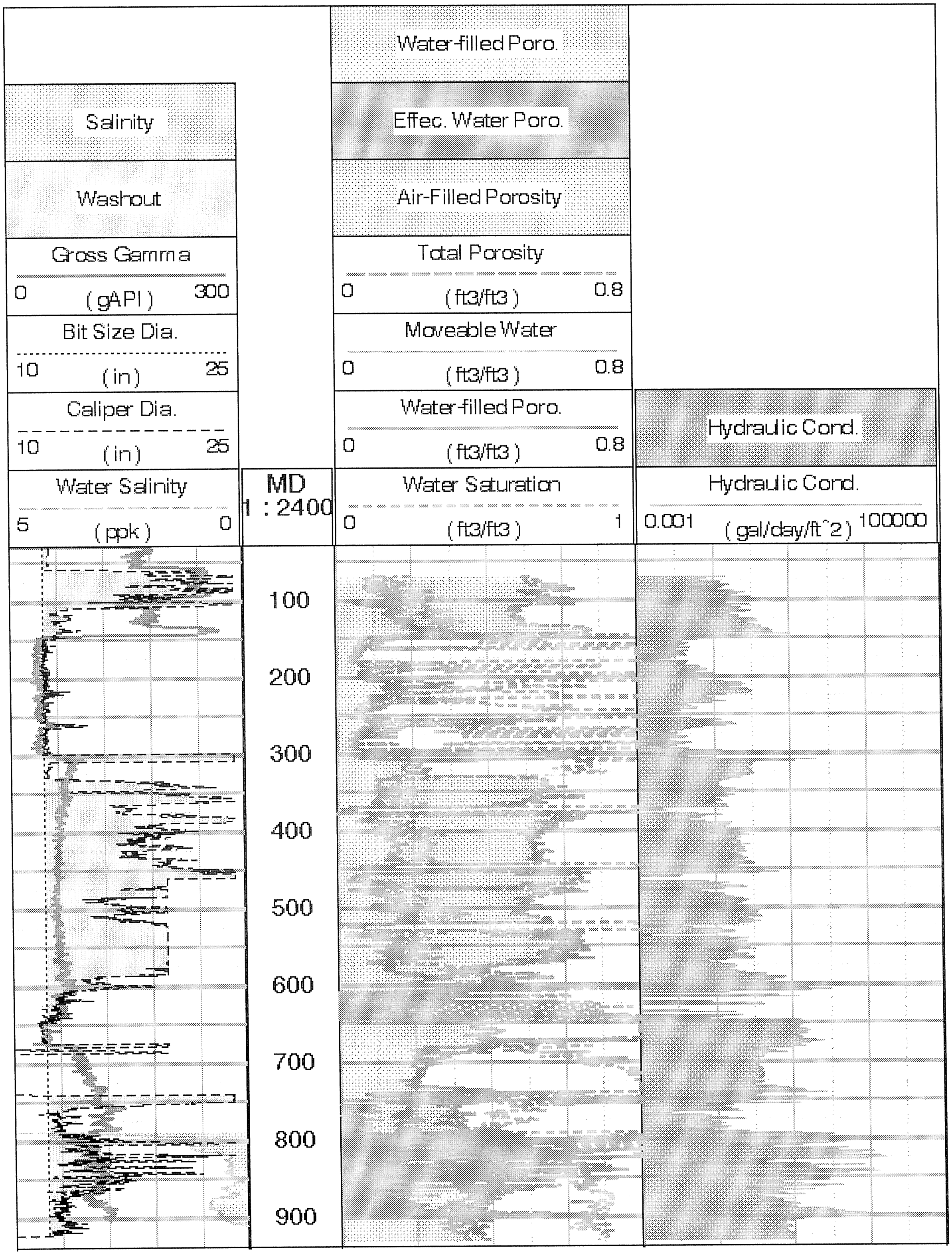

Figure 4.1. **Summary of porosity logs in R-34 borehole from processed geophysical logs, interval of 71to 933 ft, with caliper, gross gamma, apparent salinity, water saturation, and water hydraulic conductivity logs. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.**

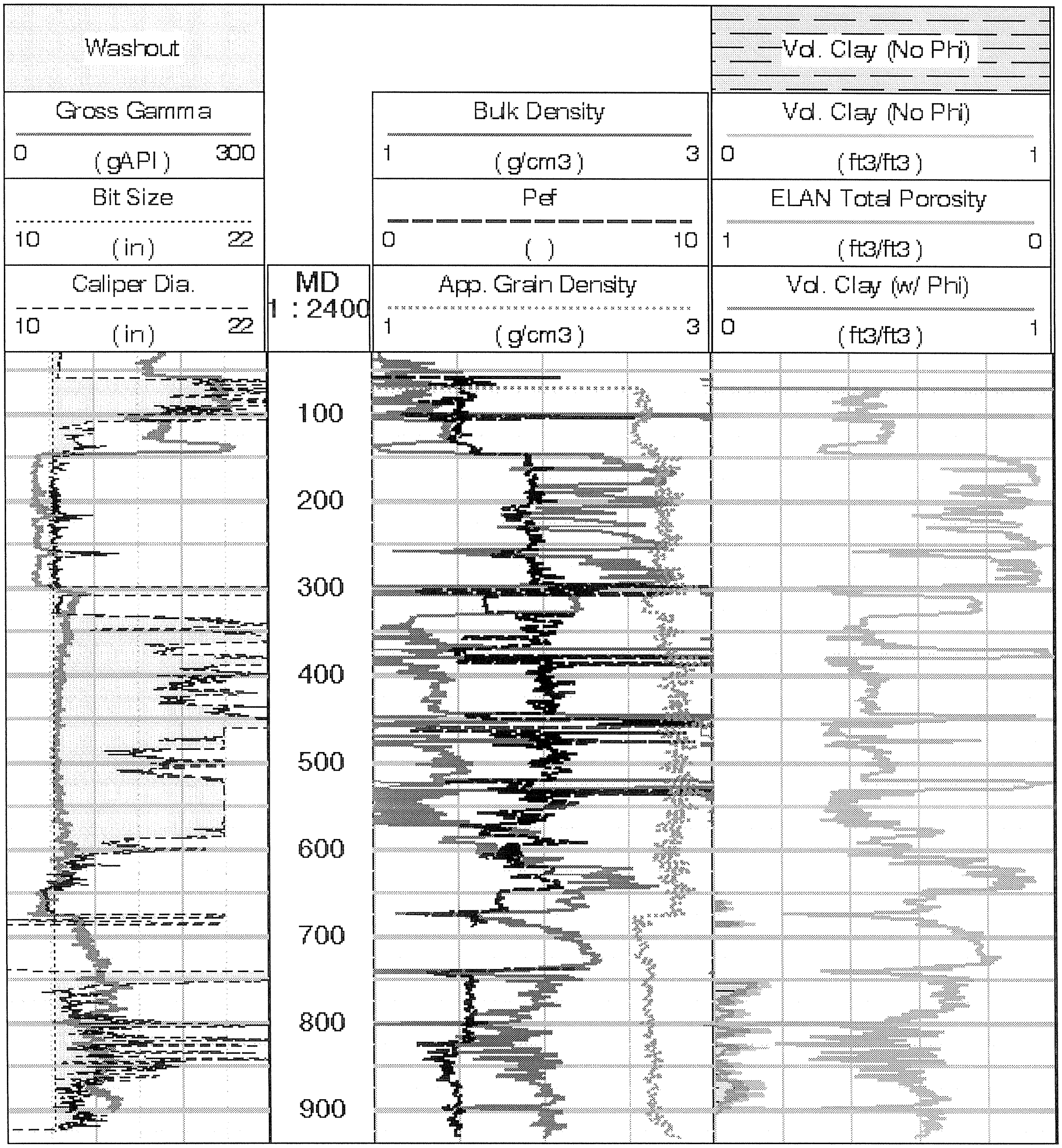

Figure 4.2. **Summary of bulk density and volume clay logs in R-34 borehole from processed geophysical logs, interval of 37 to 933 ft. Also shown are caliper, gross gamma, apparent grain density, and total porosity logs (the latter two derived from the ELAN analysis).**

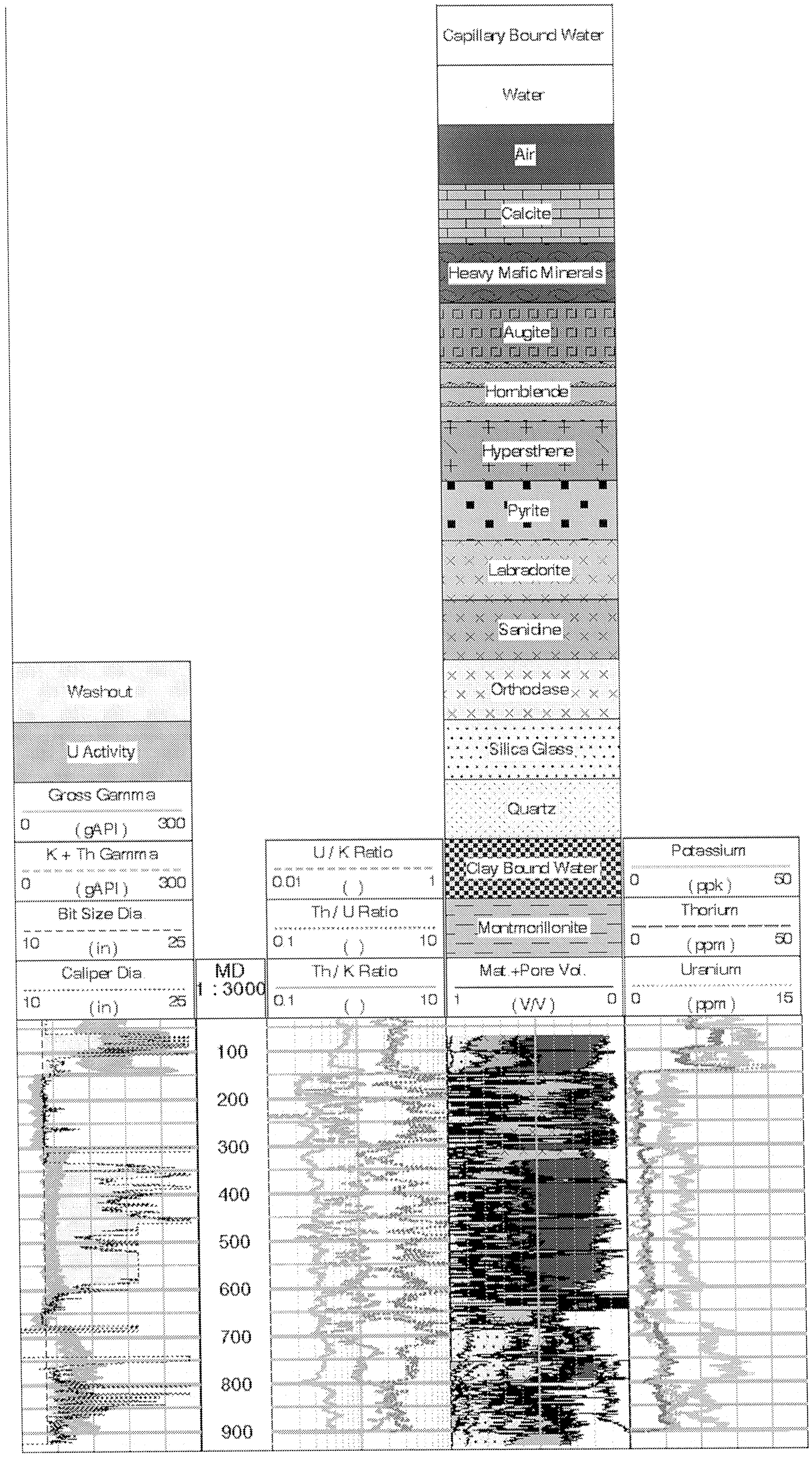

Figure 4.3. **Summary of spectral natural gamma ray logs and ELAN mineralogy/lithology and pore fluid model from R-34 borehole, interval of 31 to 933 ft. Caliper log is also shown.**

4.6 Integrated Log Montage

This section summarizes the integrated geophysical log montage for R-34. A description of each log curve in the montage follows, organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the R-34 geophysical logs are provided in the previous section.

4.6.1 Track 1–Depth

The first track on the left contains the depth below ground surface in units of feet, as measured by the geophysical logging system during the TLD-CNL-GR logging run of 3-August-2004, and the AIT-NGS logging run of 10-August-2004 (the latter run depth-matched to the former). All the geophysical logs are depth-matched to the gross gamma measurement run with these two logging runs.

4.6.2 Track 2–Basic Logs

The second track on the left (inclusive of the depth track) presents basic curves:

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 300 API units;
- two orthogonal calipers from the FMI (thin dotted and dashed pink) and one from the TLD (thin solid pink) with bit size as a reference (dashed-dotted black) to show washout (pink shading), recorded as hole diameter in inches and displayed on a scale of 11 to 26 in.;
- spontaneous potential, or SP (dashed red – valid only below the borehole water level), recorded in millivolts and displayed on a relative scale;
- bulk salinity (dashed green with green shading), recorded in parts per thousand (ppk) and displayed on a scale of 5 to 0 ppk (left to right);
- borehole deviation displayed as a tadpole every ten feet (light blue dots and connected line segments) – the "head" marks the angular deviation from vertical at that particular depth, on a scale of 0 to 5 degrees, and the "tail" shows the azimuth of the deviation, true north represented by the tail facing straight towards the top of the page.

Two gamma ray curves from the NGS are presented:

- total gross gamma (thick solid black curve) and
- gross gamma minus the contribution of uranium (dashed black).

4.6.3 Track 3–Resistivity

The third track displays the resistivity measurements from the AIT, spanning most of the open hole section at the time of the second logging. All the resistivity logs are recorded in units of ohmmeters and are displayed on a logarithmic scale of 2 to 2000 ohm-m.

Six electrical resistivity logs from the AIT contain:

- Borehole fluid resistivity (solid orange curve)–only valid in water-filled hole
- Bulk electrical resistivity at five median depths of investigation–10 in. (black solid), 20 in. (long-dashed blue), 30 in. (short-dashed red), 60 in. (dashed-dotted green), and 90 in. (solid purple)–each having a 2-foot vertical resolution. The logs are only valid (and, thus, only displayed) below the steel casing present at the time of the second logging.

The area between the 10 in. and 90 in. resistivity curves, representing radial variations in bulk resistivity (potentially from invasion of drilling fluids), is shaded:

- blue when the 10-in. resistivity is greater than the 90-in. resistivity (labeled "resistive invasive") and
- yellow when the 90-in. resistivity is greater than the 10-in. resistivity (labeled "conductive invasive").

A high vertical resolution (~8 in.), shallow-reading (~2 in.) micro-resistivity log from the MCFL is also displayed in this track (solid pink curve)–only valid in water-filled hole.

4.6.4 Track 4–Porosity

The fourth track displays the primary porosity log results. All the porosity logs are recorded in units of volumetric fraction and are displayed on a linear scale of 0.75 (left side) to -0.1 (right side). Specifically, these logs consist of

- CNT epithermal neutron porosity (solid sky blue curve)–epithermal neutron porosity processed for zoned air-filled and water-filled hole, spliced from the two separate logging acquisitions;
- CNT water-filled thermal neutron porosity (solid sky blue curve)–thermal neutron porosity valid only in the water-filled borehole, spliced from the two separate logging acquisitions;
- CMR total water-filled porosity (solid black), only valid (and, thus, only displayed) below the steel casing present at the time of the second logging;
- CMR effective water-filled porosity (dashed green), only valid (and, thus, only displayed) below the steel casing present at the time of the second logging;
- CMR bound water porosity (light blue area shading)–representing by the area between the CMR total and effective water-filled porosities;
- Total porosity derived from bulk density and ELAN water-filled porosity using a grain density of 2.65/3.05/2.85 g/cc (dotted red curve), 2.45/2.85/2.65 g/cc (long-dashed red curve), and 2.25/2.65/2.45 g/cc (dashed red curve)–with red shading between the 2.25/2.65/2.45 g/cc and 2.65/3.05/2.85 g/cc porosity curves to show the range (the highest grain density range used across the basalt interval 147–667 ft, the middle grain density range used across the fanglomerate/clastic interval 667–933 ft, and the lowest grain density range used across the tuff interval 71–147 ft); and

- ELAN total water and air-filled porosity (dashed-dotted cyan)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

4.6.5 Track 5–Density

The fifth track displays the

- bulk density (thick solid maroon curve) on a scale of 1 to 3 g/cc;
- Pe (long-dashed black curve) on a scale of 0 to 10 non-dimensional units;
- density correction (dashed orange curve) on a scale of -0.75 to 0.25 g/cc; and
- apparent grain density (dashed-dotted brown curve), derived from the ELAN analysis, on a scale of 2.5 to 3.5 g/cc.

Grey area shading is shown where the Pe increases above 3 (indicating the presence of heavy, possibly mafic, minerals), and orange shading is shown where the density correction is greater than the absolute value of 0.25 (indicating the density processing algorithm had to perform a major correction to the bulk density calculation).

4.6.6 Track 6–NGS Spectral Gamma

The sixth track from the left displays the spectral components of the NGS measurement results as wet weight concentrations:

- potassium (solid green curve) in units of parts per thousand (ppk) and on a scale of -50 to 50 ppk;
- thorium (dashed brown) in units of parts per million (ppm) and on a scale of 50 to –50 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 20 to 0 ppm.

4.6.7 Track 7–CMR Porosity

Track 7 displays various CMR water-filled porosities along with measurement quality flags–valid only in the open-hole section. The porosity and measurement quality logs are presented on a scale of 0.5 to 0 volume fraction and discrete blocks originating from the left side, respectively. Specifically, the CMR logs shown in this track are:

- Total water-filled porosity (solid black curve)–representing the total water volume fraction measured by the CMR;
- Three millisecond (ms) porosity (short-dashed brown)–representing the water volume fraction corresponding to the portion of the CMR measured T2 distribution that is above 3 ms, a cutoff that is considered to be representative of the break between clay-bound water (less than 3 ms) and all other types of water (greater than 3 ms);
- Effective water-filled, or free-fluid, porosity (solid pink)–representing the water volume fraction that is moveable (can flow), based on a 33 ms T2 distribution cutoff

that is considered representative of the break between bound water (less than 33 ms) and moveable water (greater than 33 ms) in clastic rocks;

- Clay-bound water (brown area shading between total and 3 ms porosity logs)–representing the water volume fraction that is bound within clays;
- Capillary-bound water (pink area shading between 3 ms and effective porosity logs)–representing the water volume fraction that is bound within matrix pores by capillary forces;
- CMR magnetic field variation (dotted yellow)–representing the variation in the measured magnetic field versus the baseline magnetic field used for the logging (used as an indicator of the presence of magnetic minerals which requires a lower T2 cutoff)
- CMR wait-time flag (red area shading)–activates when there is significant measurement response at late T2 times, corresponding to large amounts of completely free ("bathtub") water and often associated with washouts or very large pores;
- CMR measurement noise flag (yellow and orange area shading)–activates when there is potentially detrimental amounts of measurement noise detected by the tool, at moderate (yellow) and high (orange) levels.

4.6.8 Track 8 –Pore Size Distribution

Track 8 displays the water-filled pore size distribution as determined by the CMR–shown as binned water-filled porosities and valid only in the open-hole section. The binned porosity logs are presented on a scale of 0.5 to 0 volume fraction with colored area shading corresponding to the different bins:

- Clay-bound water–brown area shading
- Micro-pore and small-pore water (the sum comprising capillary-bound water)–gray and blue area shading, respectively
- Medium-pore, large-pore, and late-decay (the sum comprising effective water-filled porosity) water–yellow, red, and green area shading, respectively

4.6.9 Track 9–CMR T2 Distribution (Waveforms)

The CMR T2 distribution is displayed in Track 9 as green waveform traces at discrete depths. The horizontal axis, corresponding to relaxation time in milliseconds, is on a logarithmic scale from 0.3 to 3000 ms. Also plotted are the:

- T2 logarithmic mean (solid blue curve) and
- T2 cutoff time used for differentiating between bound and free water (solid red line)–a constant 33 ms, in this case.

4.6.10 Track 10–CMR T2 Distribution (Heated Amplitude)

Track 10 displays the T2 distribution in another way–on a heated color scale where progressively "hotter" color (green to yellow to red) corresponds to increasing T2 amplitude. The remaining aspects of the display are the same as in Track 9, except that the T2 logarithmic mean is shown as a solid white curve and the T2 cutoff is not displayed.

4.6.11 Track 11–CMR Hydraulic Conductivity

Track 11 displays several estimates of hydraulic conductivity (K) derived from the CMR measurement and the ELAN integrated log analysis (the latter primarily sensitive to the CMR measurement of moveable water), presented on a logarithmic scale of 10^{-4} to 106 gallons per day per feet squared (gal/day/ft^2):

- A K-versus-depth estimate derived from using the SDR permeability equation applied to the processed CMR results, converted to hydraulic conductivity (dashed purple curve);
- A K-versus-depth estimate derived from using the Timur-Coates permeability equation with total and moveable water content derived from the ELAN analysis, converted to hydraulic conductivity (solid blue curve); and
- An intrinsic K-versus-depth estimate (assuming full saturation) using the Timur-Coates permeability equation with total and effective porosity values derived from the ELAN analysis, converted to hydraulic conductivity (dotted cyan).

4.6.12 Track 12– FMI Image (Dynamic Normalization)

Track 12 displays the FMI image, processed with dynamic normalization so that small-scale electrical resistivity features are amplified in the image. (With dynamic normalization the range of electrical resistivity amplitudes – colors in the image – is normalized across a small moving depth window.) The image is fully oriented and corresponds to the inside of the borehole wall unwrapped such that the left-hand side represents true north, half-way across the image is south, and the right-hand side is north again. The four color tracks in the image correspond to portions of the borehole wall contacted by the four FMI caliper pads; the blank space in between is the portion of the borehole wall not covered by the pads.

Also displayed are the interpreted bed boundaries (thin blue sinusoids) and cross bedding (red sinusoids).

4.6.13 Track 13– FMI Bedding and Fractures

Track 13 displays the interpreted bed boundaries and cross bedding picked from the FMI image, shown in two ways:

- Individually as tadpoles at the depths the bedding plane or cross bedding crosses the midpoint of the borehole – where the “heads” (circles/triangles) represent the dip angle, and the “tails” (line segments) represent the true dip azimuth (direction the bed is dipping towards). Bed boundaries are shown as circular-headed blue tadpoles and, electrically, cross bedding is shown as circular-headed red tadpoles.
- Summed as dip azimuth fanplot histograms (green colored fan plots for bed boundaries) – where the number of bed boundaries having a dip direction within a particular sector are summed and normalized, thus highlighting the predominant dip directions.

4.6.14 Track 14– FMI Image (Static Normalization)

Track 14 displays the FMI image again, but in a different way – processed with static normalization to highlight larger-scale features and trends. (With static normalization, the range of electrical resistivity amplitudes – colors in the image – is normalized across the entire length of the log interval.) Also shown is the high-resolution-scaled resistivity from one of the FMI pads.

4.6.15 Track 15– Fracture Aperture and High Resolution Porosity

Track 15 displays the estimated hydraulic aperture of any interpreted electrically conductive fractures (red circles on logarithmic scale of 0.0001 to 1 inch) – computed using an FMI image scaled to the AIT shallow resistivity. Also displayed is the high resolution thermal neutron porosity log (solid blue) and the high resolution density porosity (solid red), the latter computed assuming a matrix grain density of 2.65 g/cc and a pore fluid density of 1.0 g/cc. Both of these logs have an 8-in.-depth resolution and have been depth-matched to the FMI image. Where the density porosity is greater than the neutron porosity, the area between the two logs is shaded red. The red shading is an indication of air in the pore space (less than 100% water saturation).

4.6.16 Tracks 16 to 20– Geochemical Elemental Measurements

The narrow tracks 16 to 20 present the geochemical measurements iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), potassium (K) and estimated aluminum (Al), titanium (Ti) and gadolinium (Gd), and hydrogen (H) and bulk chlorinity (Cl) —from left to right respectively, in units of dry matrix weight fraction (except H wet-weight fraction, Cl and K in ppk).

4.6.17 Track 21–ELAN Mineralogy Model Results (Dry-Weight Fraction)

Track 21 displays the results from the ELAN integrated log analysis (the matrix portion)– presented as dry-weight fraction of mineral types chosen in the model:

- Montmorillonite clay (brown/tan)
- Quartz (yellow with small black dots)
- Silica glass (orange)
- Orthoclase or other potassium feldspar (lavender)
- Sanidine (violet)
- Labradorite or other plagioclase feldspar (pink)
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- Calcite (cyan)
- Pyrite (cross-hatched red).

4.6.18 Track 22–ELAN Mineralogy–Pore Space Model Results (Wet Volume Fraction)

Track 22 displays the results from the ELAN-integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Montmorillonite clay (brown/tan)
- Clay-bound water (checkered gray-black)
- Quartz (yellow with small black dots)
- Silica glass (yellow with large black dots)
- Orthoclase or other potassium feldspar (lavender)
- Sanidine (violet)
- Labradorite or other plagioclase feldspar (pink)
- Pyrite (tan with large black squares).
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic minerals, such as magnetite (dark army green)
- Calcite (cyan)
- Air (red)
- Moveable water (white)
- Capillary-bound water (light blue)

4.6.19 Track 23–Summary Logs

Track 23, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools, including water saturation:

- Optimized estimate of total volume fraction water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of moveable volume fraction water (effective porosity in fully saturated conditions) from the ELAN analysis (dashed cyan curve and green area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (dashed-dotted purple curve);
- Water saturation as calculated directly from the bulk density and ELAN-estimated porosity using a grain density of 2.65/3.05/2.85 g/cc (dotted light blue curve), 2.45/2.85/2.65 g/cc (long-dashed light blue curve), and 2.25/2.65/2.45 g/cc (dashed light blue curve)–with light blue shading between the 2.25/2.65/2.45 g/cc and 2.65/3.05/2.85 g/cc porosity curves to show the range (the highest grain density range used across the basalt interval 147–667 ft, the middle grain density range used across

the fanglomerate/clastic interval 667–933 ft, and the lowest grain density range used across the tuff interval 71–147 ft);

- Integrated estimated relative water flow from the ELAN water permeability log that mimics a flow meter (spinner) acquired under flowing conditions (solid green line coming from left-hand side at bottom of logged interval);
- Potential for water flow indicator from the CMR log (block cyan coming from the right-hand side of the track).

The porosity curve scale is from 0 to 1 total volume fraction, left to right; the water saturation scale is from 0 to 1 volume fraction of pore space, from left to right. The relative water flow is on a scale of 0 to 1 relative volumetric flow rate from left to right. The flow indicator is a binary-valued flag that rises to halfway through the first division from the right on the X-axis when the CMR measurement indicates a potential for flow.

4.6.20 Track 24–Depth

The final track on the right, the same as the first track on the left, displays the depth below ground surface in units of feet, as measured by the geophysical logging system during the first logging (TLD-CNT-GR) – spliced to the AIT-NGT logging run acquired during the second logging.

5.0 REFERENCES

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Appendix D

Lithologic Log

LITHOLOGIC LOG

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Qal, Alluvium	Unconsolidated sediments; silt (ML); light brown (5YR 6/4) to pale brown (5YR 5/2); fines with trace sands; poorly indurated; +10F (i.e., >#10 sieve-size fraction): 30-40% tuff fragments, 30-40% intermediate volcanics (porphyritic dacite noted), 30-40% crystals (frequent dipyramidal quartz observed), clasts angular to rounded; +35F (i.e., >#35 sieve-size fraction): 30-40% tuff/pumices, 30-40% intermediate volcanics, 30-40% crystals. **Note: Descriptions presented in this lithologic log are primarily based on observations made during visual examination of the drill cuttings. Stratigraphic contacts are based on available information from review of cuttings and geophysical logs. Lithologies encountered during drilling, however, resulted in borehole instability and lost circulation, producing sections of poor or intermixed cuttings and limited intervals for geophysical logging.**	0-18	6629.99 (6630) - 6612
Qbt1g, Tshirege Member of the Bandelier Tuff	Unconsolidated sediments intermixed with tuff; light brown (5YR 6/4) to pale brown (5YR 5/2); silt (ML) intermixed with sparse clasts of white vitric pumices and poorly to moderately welded tuff fragments; +10F: intermixed fragments of siltstone, sandstone, devitrified tuff fragments, vitric pumices with occasional felsic phenocrysts; +35F: composition similar to +10F. **Note: The base of the alluvium and contact with the underlying Tshirege Member of the Bandelier Tuff is estimated to be at 18 ft bgs based on observations during drilling.**	18-20	6612-6610
	Volcanic tuff; grayish orange pink (5YR 7/2); poorly welded; pumice-rich; +10F: 70-75% vitric fibrous pumice up to 3 cm with occasional felsic phenocrysts and trace black phenocrysts, 10-15% tuff fragments, 10-15% lithics including dacite up to 3.5 cm and broken to rounded; +35F: 50-60% pumices, 30-40% crystals, 5-10% lithics and tuff fragments.	20-35	6610-6595
	Volcanic tuff; grayish orange pink (5YR 7/2); poorly welded; pumice-rich; +10F: 85-90% vitric white pumices with mafic and felsic phenocrysts, 8-10% intermediate volcanic lithics including dacite up to 1 cm and subangular, 3-5% moderately welded tuff fragments; +35: 45-50% pumices, 45-50% crystals, 2-5% lithics.	35-50	6595-6580
	Volcanic tuff; very pale orange (10YR, 8/2); poorly welded, pumice-rich. +10F: 90-95% white, vitric pumices, up to 3 cm with occasional felsic phenocrysts; 5-10% lithics, intermediate volcanics and obsidian noted, up to 0.5 cm; +35F: 60-70% pumices and tuff fragments, 30-40% crystals, 2-5% lithics.	50-60	6580-6570

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	No cuttings returned; no sample available for examination.	60-65	6570-6565
	Volcanic tuff; very pale orange (10YR 8/2); poorly welded; +10F: 50-60% vitiric fibrous pumice with occasional felsic phenocrysts and <1-mm, rare black phenocrysts, 40-50% tuff fragments, 10-15% lithics including intermediate volcanics and occasional black vitrophyre; +35F: 30-50% pumices, 50-80% crystals (predominantly quartz and sanidine), 5-10% lithics.	65-85	6565-6545
Qbo, Otowi Member of the Bandelier Tuff	Volcanic tuff; grayish yellow (5Y 8/1); poorly welded; +10F: 50-60% white vitric fibrous pumice (up to 0.8 cm) with occasional felsic phenocrysts and trace black phenocrysts, 40-50% tuff fragments up to 0.7 cm, 10-15% lithics including intermediate volcanics and trace black vitrophyre; +35F: 30-40% pumice, 60-70% crystals (predominantly quartz/sanidine), 2-5% lithics. **Note: the base of the Tshirege Member and contact with the underlying Otowi Member is interpreted to be at 96 ft bgs.**	85-100	6545-6530
	Volcanic tuff; grayish orange pink (5YR 7/2); poorly welded, lithic-rich; +10F: 50-60% reddish and gray volcanic lithic fragments, mostly Fe-stained dacite with minor vesicular basalt (up to 0.8 cm), 40-50% reddish pumice, minor white pumice, 0-2% quartz and sanidine crystals; +35F: 20-30% pumice, 30-40% crystals (predominantly quartz and sanidine crystals), 20-30% lithics.	100-110	6530-6520
	Volcanic tuff, moderate orange pink (5YR 8/4) to grayish orange pink (5YR 7/2), poorly welded; +10F: similar to previous interval, 50-60% reddish and gray volcanic lithic fragments, 40-50% pumice, 0-2% quartz and sanidine crystals. +35F: 20-30% pumice, 30-40% crystals, dominantly quartz and sanidine, 20-30% lithics, predominately dacite fragments.	110-130	6520-6500
Qbog, Guaje Pumice Bed	Volcanic tuff; grayish orange pink (5YR 7/2), poorly welded; +10F: 40-50% pumice, partially altered, white, 0-2% crystals, 50-60% intermediate volcanics including dacite, Fe staining noted; +35F: 20-30% pumices, 30-40% crystals, 20-30% lithics. **Note: the base of the Otowi Member and contact with the underlying Guaje Pumice Bed is interpreted to be at 134 ft bgs.**	130-140	6500-6490
Tb, Cerros del Rio Basalt	Volcanic tuff, grayish orange pink (5YR 7/2) to light brown (5YR 6/4); poorly welded; +10F: little to no recovery; +35F: 35-40% pumice, 35-40% crystals, 20-30% lithics. **Note: the base of the Guaje Pumice Bed and the underlying Cerros del Rio basalt is interpreted to be at 146 ft bgs.**	140-150	6490-6480

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Basalt with intermixed Bandelier Tuff cuttings circulated from stratigraphically higher horizons; light brownish gray (5YR 6/1) to medium light gray (N6); +10F: 80% vesicular basalt fragments, 15-20% tuff and pumice fragments; +35F: 70-75% basalt fragments, 25-30% pumice, 0-5% crystals.	150-155	6480-6475
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium gray (N5); +10F: similar to previous interval, basalt fragments up to 0.9 cm with some tuff, pumice, and dacite fragments; +35F: 90-95% basalt with minor dacite, 5-10% pumice and quartz/sanidine crystals.	155-160	6475-6470
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium gray (N5); WR (whole rock or unsieved sample)/+10F: similar to previous interval, slightly vesicular basalt fragments (up to 2.7 cm), porphyritic (olivine phenocrysts) with aphanitic groundmass fragments also observed; +35F: 95-100% basalt, 0-5% pumice and crystals (quartz and sanidine).	160-180	6470-6450
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium gray (N5); WR/+10F: vesicular and massive (fine grained) basalt fragments up to 2.0 cm; +35F: basalt with minor pumice and crystals (quartz and plagioclase).	180-185	6450-6445
	Basalt; medium light gray (N6) to medium gray (N5); WR/+10F: basalt fragments up to 2 cm, porphyritic with aphanitic groundmass, and vesicular, mafic phenocrysts including olivine, frequently mottled red; +35F: basalt fragments, minor Fe-staining.	185-200	6445-6430
	Basalt; medium light gray (N6) to medium gray (N5); WR/+10F: similar to previous interval, massive to slightly vesicular basalt fragments (up to 1.9 cm); +35F: basalt, possible scoria fragment; basalt has minor Fe-staining.	200-210	6430-6420
	No cuttings returned; no sample available for examination.	210-225	6420-6405
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium gray (N5); WR/+10F: massive basalt fragments (up to 0.7 cm), minor pumice from intermixing from material uphole; +35F: 95% basalt, minor Fe-staining; 5% pumice and quartz/sanidine crystals.	225-235	6405-6395
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium gray (N5); WR/+10F: massive aphanitic basalt and vesicular basalt fragments (up to 2.1 cm), vesicular fragments frequently reddish brown, minor clay lining of vesicles, occasional phenocrysts. +35F: 95% basalt, minor Fe-staining; 5% pumice and crystals (quartz and sanidine).	235-260	6395-6370
	No cuttings returned; no sample available for examination.	260-265	6370-6365

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium dark gray (N4); WR/+10F: basalt up to 2.1 cm, vesicular, weathered, possible scoria up to 2.6 cm; +35F: 95% basalt with some Fe-staining, minor crystals (quartz and sanidine), and scoria.	265-270	6365-6360
	Basalt with intermixed tuff cuttings; medium light gray (N6) to medium dark gray (N4); WR/+10F: slightly vesicular basalt (up to 1.5 cm), aphanitic groundmass with 2-5% phenocrysts, basalt fragments up to 2.1 cm, minor scoria (up to 2.9 cm); +35F basalt with some Fe-staining; minor pumice and crystals (quartz and sanidine).	270-300	6360-6330
	Basalt/scoria; medium light gray (N6) to dark reddish brown (10R 3/4); WR/+10F: 55% basalt fragments (massive to vesicular, up to 2.3 cm), 20% scoria, (up to 2.8 cm); +35F: 95% basalt, 5% scoria; minor pumice intermixed from uphole.	300-305	6330-6325
	No cuttings returned; no sample available for examination.	305-315	6325-6315
	Scoria/basalt; dark reddish brown (10R 3/4) to medium light gray (N6); WR/+10F: 65% scoria (up to 0.6 cm), 35% basalt; +35F: 60% scoria, 40% basalt, trace vitric basalt fragments.	315-320	6315-6310
	Scoria; dark reddish brown (10R 3/4) to medium light gray (N6); WR/+10F: predominantly scoria (up to 3.3 cm), minor basalt (up to 0.8 cm); +35F: 70-80% scoria, 20-30% basalt.	320-335	6310-6295
	Scoria; dark reddish brown (10R 3/4) to medium light gray (N6); WR: 90-95% scoria, 5-10% basalt fragments; +10F: scoria (up to 1.2 cm), minor basalt, occasional vitric basalt fragments; +35F: 85-90% scoria, 10-15% vitric basalt fragments, trace basalt.	335-350	6295-6280
	No cuttings returned; no sample available for examination.	350-370	6280-6260
	Scoria with intermixed tuff cuttings; dark reddish brown (10R 3/4) WR: 75% scoria, 5% basalt, 20% fines; +10F: scoria fragments (up to 1.8 cm), trace vesicular basalt (up to 1.9 cm); 50% of fragments have vitric appearance; +35F: 90-95% scoria, 5% basalt, minor quartz and sanidine crystals.	370-380	6260-6250
	Scoria; dark reddish brown (10R 3/4); WR: predominantly scoria fragments with lesser amounts of basalt fragments, coated with reddish fines; +10F: scoria fragments (up to 3.0 cm), trace vesicular basalt fragments; +35F: scoria, minor crystals, frequent vitric fragments.	380-405	6250-6225
	Scoria with intermixed tuff cuttings; dark reddish brown (10R 3/4). WR: predominantly scoria fragments with lesser amounts of basalt fragments, coated with reddish fines; +10F: predominantly scoria (up to 3.2 cm) with minor vesicular basalt coated with reddish clay-sized fines; +35F: 60-70% scoria, 30-40% basalt, minor crystals (quartz and sanidine) and pumice.	405-425	6225-6205
	No cuttings returned; no sample available for examination.	425-455	6205-6175

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Scoria with intermixed tuff cuttings; dark reddish brown (10R 3/4); WR/+10F: predominantly scoria (up to 2.0 cm), numerous vitric scoria fragments, felsic phenocrysts up to 2 mm, minor vesicular basalt and pumice; +35F: 90% scoria, 5% basalt, 5% vitric basalt fragments, minor crystals (quartz and sanidine) and pumice.	455-465	6175-6165
	No cuttings returned; no sample available for examination.	465-475	6165-6155
	Scoria; dark reddish brown (10R 3/4); WR/+10F: predominantly scoria (up to 1.0 cm), numerous vitric fragments, minor porphyritic basalt, plagioclase phenocrysts, minor pumice; +35F: 80% scoria, 15% basalt, minor olivine crystals.	475-485	6155-6145
	No cuttings returned; no sample available for examination.	485-490	6145-6140
	Scoria; dark reddish brown (10R 3/4); WR: scoria and basalt fragments with fines; +10F: 90% scoria (up to 1.5 cm) containing trace amounts of lithic/ mafic phenocrysts and frequent vitric scoria, 10% basalt with local white to brown clay filling some vesicles; +35F: 80% scoria, 15% basalt, and minor plagioclase and olivine crystals.	490-500	6140-6130
	Scoria with intermixed tuff cuttings; moderate reddish brown (10R 4/6) to dark reddish brown (10R 3/4); WR: similar to previous interval; +10F: scoria (up to 3.0 cm), reddish brown to dark gray, trace infilling voids with fines, trace phenocrysts; +35F: little to no recovery, 70-80% scoria, 15-20% basalt, minor quartz and sanidine crystals.	500-510	6130-6120
	No cuttings returned; no sample available for examination.	510-520	6120-6110
	Scoria with intermixed tuff cuttings; moderate reddish brown (10R 4/6) to medium gray (N5); WR: scoria, 20% basalt, 2-3% pumice fragments; +10F: scoria fragments (reddish brown to dark gray, up to 1.0 cm), numerous vitric fragments, trace basalt and pumice; +35F: 70-80% scoria, 15-20% basalt, minor crystals (quartz and sanidine) and pumice.	520-525	6110-6105
	No cuttings returned; no sample available for examination.	525-530	6105-6100
	Scoria with intermixed tuff cuttings; moderate reddish brown (10R 4/6) to medium gray (N5); WR: scoria, 20% basalt, 2-3% pumice fragments; +10F: scoria fragments (reddish brown to dark gray, up to 1.0 cm), numerous vitric fragments, trace basalt and pumice; +35F: 70-80% scoria, 15-20% basalt, minor crystals (quartz and sanidine) and pumice.	530-550	6100-6080
	No cuttings returned; no sample available for examination.	550-565	6080-6065

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Scoria with intermixed basalt cuttings; moderate reddish brown (10R 4/6) to grayish black (N2); WR: 65-70% fines, 30-35% scoria fragments, trace basalt; +10F: 85-90% scoria (dark red to grayish black) and occasional glassy scoria with fragments up to 2 cm containing trace amounts of phenocrysts, 10-15% basalt fragments including aphanitic groundmass with phenocrysts of olivine/other crystals, vesicular basalt, occasional subrounded fragments; +35F: 80% scoria, 15% basalt; 5% quartz/sanidine and pumice intermixed from uphole.	565-595	6065-6035
	Scoria; dark red brown (10R 3/4) to grayish black (N2) with trace basalt lava fragments; +10F: scoria (up to 0.5 cm), 60-80% reddish brown fragments, 20-40% blackish gray fragments tending towards highly vesicular basalt lava; +35F: scoria and minor basalt, minor crystals.	595-615	6035-6015
	Scoria with intermixed basalt cuttings; red (5R 3/4) to dark gray (N3) with trace basalt; +10F: similar to previous interval, 70% scoria (up to 1.5 cm), 30% dark gray scoria fragments tending towards highly vesicular basalt lava, massive basalt; +35F: 60% scoria, 35% basalt; minor crystals (quartz, sanidine, olivine) and pumice intermixed from uphole. **Note: Drilling encountered more resistant material at 628 ft bgs.** Based on geophysical logs, base of scoria and top of base interpreted to be 610 ft bgs.	615-630	6015-6000
	Basalt with intermixed tuff cuttings; medium light gray (N6); WR/+10F: 70-80% basalt fragments (up to 1.0 cm), porphyritic with aphanitic groundmass and vesicular, 15-25% scoria, trace pumice; +35F: 70-80% basalt, 15% scoria, 5-15% quartz crystals and pumice.	630-635	6000-5995
	No cuttings returned; no sample available for examination.	635-655	5995-5975
	Basalt with intermixed tuff cuttings; medium light gray (N6); WR/+10F: 70-80% basalt fragments (massive and porphyritic with aphanitic groundmass), 20-30% scoria with gray clay-sized particles locally coating basalt and scoria fragments and partially filling vesicles; +35F: 75% basalt, 20% scoria, 5% olivine with quartz and pumice grains.	655-665	5975-5965
Ta, Older Alluvium	No cuttings returned; no sample available for examination. **Note: Based on borehole geophysical logs, the base of the Cerros del Rio basalt and the top of the Older Alluvium is interpreted to be 678 ft bgs.**	665-685	5965-5945

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Volcaniclastic sediments with intermixed basalt cuttings; medium blue gray (5B 5/1); WR/ +10F: 70% basalt (massive and porphyritic with aphanitic groundmass), 15% scoria, minor pumice; +35F: 65% basalt, 20% scoria; 10% pumice crystals intermixed from uphole, minor quartz crystals (frosted quartz likely introduced to borehole during repair to washout at 300 ft bgs). These cuttings largely reflect poor circulation in the borehole and consist mainly of geologic units above the older alluvium.	685-690	5945-5940
	No cuttings returned; no sample available for examination.	690-695	5940-5935
	Basalt; medium gray (N5); WR/+10F: 60% basalt fragments, 30% scoria fragments, 10% pumice and siltstone; +35F: 60% basalt, 15% scoria, 15% siltstone, 10% quartz crystals. These cuttings largely represent geologic units above the older alluvium.	695-700	5935-5930
Ta, Older Alluvium (Unassigned Formation)	Volcaniclastic sediments; light gray (N7); silty gravel (GM) with gravel clasts broken to rounded (up to 2.0 cm); +10F: clasts composed of basalt, scoria, and various clastic rocks (possible intermediate volcanics), subrounded to round.	700-705	5930-5925
	Volcaniclastic sediments; brownish gray (5YR 4/1); silty gravel with sand (GM); +10F: gravel clasts broken to subrounded (up to 2.0 cm) and composed of mostly intermediate volcanics, basalt, scoria with lesser amounts of porphyritic rhyolite, quartzite, and various clastic rocks (sandstone). **Note: The base of the Older Alluvium (unassigned formation) and contact with the underlying Puye Formation (pumiceous) is interpreted to be at 725 ft bgs.**	705-725	5925-5905
Tpp, Pumiceous Sediments of the Puye Formation	No cuttings returned; no sample available for examination.	725-740	5905-5890
	Pumiceous volcaniclastic sediments with intermixed basaltic scoria cuttings circulated from stratigraphically higher horizons; grayish red (5R 4/2); pumiceous sand (SP); +10F: clasts composed of 70% scoria, 15% quartz, 15% basalt, quartzite, pumice (white, vitric); gravel clasts subrounded; +35: fine to medium sand (subangular to subrounded), consisting of 40% scoria, 30% quartz, 20% pumice, 10% basalt fragments.	740-745	5890-5885
	No cuttings returned; no sample available for examination.	745-775	5885-5855
	Pumiceous volcaniclastic sediments with intermixed cuttings from stratigraphically higher horizons; medium light gray (N6); pumiceous silty sand (SM); +10F: coarse sand to gravels up to 1 cm, subangular to subrounded and consisting of 50% intermediate volcanic clasts, 30% scoria, and 20% pumice (white, vitric)/quartz/sandstone; +35F: subrounded clasts of 40% quartz/quartzite, 30% scoria, 20% pumice, 10% basalt.	775-785	5855-5845

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Pumiceous volcaniclastic sediments with intermixed cuttings from stratigraphically higher horizons; grayish orange (10YR 7/4), pumiceous, poorly graded sand (SP); +10F: 70-80% white, vitric pumice; 15% scoria; 5-15% fragments of sandstone and quartzite; coarse sand size; subrounded. +35: 40% scoria, 30% quartz, 20% pumice, and 10% basalt/quartzite.	785-795	5845-5835
	No cuttings returned; no sample available for examination.	795-800	5835-5830
	Pumiceous volcaniclastic sediments with intermixed cuttings from stratigraphically higher horizons; pale brown (5YR 5/2); poorly graded sand (SP); very fine to medium sand; clay fines present; +10F: abundant white vitric pumice and quartz with varying amounts of scoria, basalt, and sanidine; poor returns; +35F: 50-60% scoria, 40-50% pumice and crystals.	800-825	5830-5805
	No cuttings returned; no sample available for examination.	825-840	5805-5790
	Pumiceous volcaniclastic sediments with intermixed cuttings from stratigraphically higher intervals; pale brown (5R 5/2); poorly graded sand (SP); very fine to medium sand; +10F: abundant white, vitric pumice, scoria; +35F: 60-70% pumice, 25-30% quartz and sanidine, minor dacite.	840-845	5790-5785
	No cuttings returned; no sample available for examination.	845-1000	5785-5630
	Poor recovery - small amount retained as unsieved sample only; pumiceous volcaniclastic sediments with intermixed cuttings from stratigraphically higher intervals; very pale orange (10YR 8/2) to pale brown (5R 5/2); pumiceous sand (SP); WR: 40-50% pumice, 40-50% quartz/sanidine, minor scoria, dacite, basalt.	1000-1005	5630-5625
	No cuttings returned; no sample available for examination.	1005-1020	5625-5610
	Poor recovery - small amount retained as unsieved sample only; pumiceous volcaniclastic sediments with intermixed cuttings from stratigraphically higher intervals; very pale orange (10YR 8/2) to pale brown (5R 5/2); pumiceous, poorly graded sand (SP); WR: 65-75% white, vitric pumice, 15-20% scoria, 15-25% quartz/sanidine.	1020-1025	5610-5605
	No cuttings returned; no sample available for examination.	1025-1040	5605-5590
Tpt, Totavi Lentil of the Puye Formation	No cuttings returned; no sample available for examination. **Note: The base of the pumiceous sediments and contact with the underlying Totavi Lentil is interpreted to be at 1050 ft bgs.**	1040-1060	5590-5570

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Riverine deposits with intermixed cuttings from stratigraphically higher intervals; grayish orange pink (5YR 7/2); well graded gravel (GW) with sand; +10F: varied clasts composed of 50% granitic and intermediate volcanics (possible quartzite), subrounded to rounded, with clasts up to 1.5 cm, 20-30% white to pale orange vitric pumice, 20-30% scoria. +35F: 40-45% scoria fragments, 25-30% intermediate volcanic fragments, 10-15% crystals, 10-15% pumices.	1060-1065	5570-5565

SW Well-graded sand
SP Poorly graded sand
WR Whole Rock
GW Well-graded gravel with sand
GM Silty gravel
ML Silt
SM Silty sand

Source:

ASTM D 2488-90, "Standard Practice and Identification of Soils (Visual-Manual Procedure)."

Appendix E

Aquifer Testing Report and Test Data

R-34 PUMPING TEST ANALYSIS

Table of Contents

1.0 INTRODUCTION

This section describes the analysis of constant-rate pumping tests conducted in September 2004 on R-34 in Mortandad Canyon. The primary objective of the analysis was to determine the hydraulic properties of the sediments screened in R-34. Consistent with the protocol used in recent pumping tests, the R-34 testing incorporated an inflatable packer above the pump to minimize barometric effects and to try to eliminate the effects of casing storage on the measured data.

R-34 was completed with 22.9 feet of screen, installed between the depths of 883.7 feet and 906.6 feet, in the Puye Formation. At the time of testing, the static water level was 796.5 feet below the top of the surface casing, or about 792.5 feet below land surface. The original pilot hole for the well was drilled to 1065 feet, still in the Puye, making the minimum thickness of saturated Puye Formation 272.5 feet (1065 feet minus 792.5 feet).

Testing of R-34 occurred in several phases. Initial, brief trial tests were conducted on September 11, followed by background data collection from September 11 to September 13. On September 13, an attempt was made to initiate the 24-hour constant-rate pumping test, but the pump would not produce water on a consistent basis.

The pump and transducer were pulled to allow for examination of the transducer data and testing of the pump under controlled conditions at the surface. During the pump pull, as each section of drop pipe was removed, visual observation of the water filling the remaining drop pipe hanging in the well revealed a continuous flow of air bubbles from within the drop pipe to the surface. That is, it appeared that air that had been dissolved in the water in the pipe was steadily coming out of solution. Once the pump was removed from the well, it was tested and found to perform normally.

From an examination of the recorded water level data and the other available evidence, it was eventually concluded that dissolved air in the formation was coming out of solution in response to the pressure reduction (drawdown) associated with pumping the well. The entrained air had interfered with pump operation, causing the pumping rate to fluctuate during the trial tests and hindering operation during the attempted start of the constant-rate test.

During the drilling of R-34, it was noted that substantial quantities of air were injected into the subsurface sediments. As evidence of this, following completion of the drilling and prior to running casing, on two separate occasions, the well spontaneously ejected large quantities of air and foam at the surface.

Prior to testing, it is probable that, under ambient pressures, portions of the aquifer were at saturated or near-saturated conditions with respect to air. Under these conditions, the pressure reduction caused by drawing down the water level in the well would cause de-gassing of the water, forming small air bubbles analogous to what occurs when popping the top of a canned beverage. Running even small amounts of air through a submersible pump causes it to pump erratically. Also, it appears that, during background monitoring, sufficient gas built up in the casing around the pump, beneath the inflated packer, to prevent the pump from working altogether.

Because of the concern about air buildup beneath the packer, the decision was made to conduct the 24-hour pumping test with the packer deflated (so air could escape past the packer during the test) and to inflate the packer just before shutdown. It was hoped that this approach would provide a recovery data set free of the effects of barometric pressure changes and casing storage.

The pump was rerun on September 14 and was operated briefly to verify operation and to fill the drop pipe. The constant-rate pumping test was begun at 6:04 a.m. on September 15 and continued until 6:04 a.m. on September 16, with an average pumping rate of 19.4 gallons per minute (gpm). Following shutdown, recovery data were recorded for 24 hours before tripping the pump out of the well.

2.0 INITIAL PUMPING TRIALS

Figure 1 shows water level data recorded during the first pump installation. Trials 1 and 2 were brief pumping events conducted on September 11. Note that the resulting drawdown traces are jagged, suggesting erratic pumping rates. The irregular pumping rates were confirmed by direct measurement at the surface. This response was consistent with air entrainment and its effect on pump operation.

Of great significance is that, following pump shutdown, the water level rose to a position above the static water level. It was theorized that the air bubbles that had formed around the well filled a significant volume of aquifer porosity that was formerly filled with water. The added gas volume would be expected to have the same effect as adding a similar volume of water. In other words, the formation of significant gas volume in the formation pores would have about the same effect as an injection/recharge event – it would cause water level mounding.

Furthermore, the presence of the gas phase would be expected to significantly reduce the formation hydraulic conductivity. With the reduced hydraulic conductivity, dissipation of the groundwater mound would proceed slowly because fluid movement would be impeded by the reduced conductivity. Note that following Trial 2, mounding persisted for about nine hours.

Static conditions were restored at around 7:00 a.m. on September 12. The subsequent 24-hour period provided a background data set for comparing to barometric pressure at the site.

Following the background monitoring period, an attempt was made to initiate the 24-hour constant-rate pumping test. However, initial pump startup did not produce water. It was hypothesized that the pump bowls were air locked. Eventually, the pump produced water briefly, as indicated by the Trial 3 drawdown spike on Figure 1. Because of the inability to pump consistently, the pump was pulled and tested, as discussed above.

3.0 BACKGROUND DATA

The background water level data collected in conjunction with running the pumping test allow the analyst to see what water level fluctuations occur naturally in the aquifer and help to distinguish between water level changes caused by conducting the pumping test and changes associated with other causes.

Background water level fluctuations have several causes, among them barometric pressure changes, operation of other wells in the aquifer, earth tides, and long-term trends related to weather patterns. The background data hydrograph from the R-34 tests was compared to barometric pressure data from the area to determine if a correlation existed.

Previous pumping tests have demonstrated a barometric efficiency for most wells of between 90 and 100 percent. Barometric efficiency is defined as the ratio of water level change divided by barometric pressure change, expressed as a percentage. In the early pumping tests conducted as part of this project, downhole pressure was monitored using a *vented* transducer. This equipment measures the *difference* between the total pressure applied to the transducer and the barometric pressure, this difference being the true height of water above the transducer.

Subsequent pumping tests, including R-34, have utilized a *non-vented* transducer. This device simply records the total pressure on the transducer; that is, the sum of the water height plus the barometric pressure. This results in an attenuated "apparent" hydrograph in a barometrically efficient well. Take as an example a 90 percent barometrically efficient well. When monitored using a vented transducer, an *increase* in barometric pressure of 1 unit causes a *decrease* in recorded down-hole pressure of 0.9 units, because the water level is forced downward 0.9 units by the barometric pressure change. However, using a non-vented transducer, the total measured pressure increases by 0.1 units (the combination of the barometric pressure increase and the water level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency, and in the same direction as the barometric pressure change, rather than in the opposite direction.

Barometric pressure data were obtained from the Los Alamos National Laboratory Technical Area (TA)-54 tower site from RRES-Meteorology and Air Quality. The TA-54 measurement location is at an elevation of 6548 feet above mean sea level (amsl), whereas the wellhead elevation was estimated to be roughly 6700 feet amsl. Furthermore, the static water level in R-34 was about 792 feet below land surface, making the water table elevation approximately 5908 feet amsl. Therefore, the measured barometric pressure data from TA-54 had to be adjusted to reflect the pressure at the elevation of the water table within R-34.

The following formula was used to adjust the measured barometric pressure data:

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R} \left(\frac{E_{R34} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R34}}{T_{WELL}} \right) \right],$$

where

P_{WT} = barometric pressure at the water table inside R-34
P_{TA54} = barometric pressure measured at TA-54
g = acceleration of gravity, in meters (m)/sec^2 (9.80665 m/sec^2)
R = gas constant, in Joules (J)/kilogram (Kg)/degree Kelvin (287.04 J/Kg/degree Kelvin)
E_{R34} = land surface elevation at R-34, in feet (roughly 6700 feet)
E_{TA54} = elevation of barometric pressure measuring point at TA-54, in feet (6548 feet)
E_{WT} = elevation of the water level in R-34, in feet (roughly 5908 feet)

T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 70 degrees Fahrenheit, or 294.3 degrees Kelvin)

T_{WELL} = air temperature inside R-34, in degrees Kelvin (assigned a value of 68 degrees Fahrenheit, or 293.2 degrees Kelvin)

This formula is an adaptation of an equation provided by RRES-Meteorology and Air Quality. It can be derived from the ideal gas law and standard physics principles. An inherent assumption in the derivation of the equation is that the air temperature between TA-54 and the well is temporally and spatially constant, and that the temperature of the air column in the well is similarly constant.

The corrected barometric pressure data reflecting pressure conditions at the water table were compared to the water level hydrograph to discern the correlation between the two.

4.0 THICK AQUIFER RESPONSE

A complicating aspect of the R-well pumping tests is that the wells are severely partially penetrating. The typical well design incorporates a relatively short well screen (a few feet to tens of feet in length) installed within a massively thick aquifer (many hundreds of feet or more).

As a result, during pumping, the cone of depression expands not only horizontally, but also vertically, throughout the test. As the cone intercepts a greater and greater aquifer thickness, the data plot reflects a steadily flattening slope, corresponding to the continuously increasing vertical height of the zone of investigation. As a result, later data tend to produce a greater calculated transmissivity than do early data. This complicates the analysis because, for any given slope (or transmissivity value), it is not possible to know what the corresponding aquifer thickness is (vertical extent of the cone of depression).

If an aquitard is encountered at depth, limiting the vertical growth of the cone of depression, the data curve may reach a steady slope, reflecting the transmissivity of the sediments above the aquitard. In that case, a definitive transmissivity can be determined and the hydraulic conductivity can be calculated by dividing the transmissivity by the saturated thickness above the aquitard (if that dimension is known). If no aquitard is encountered, the drawdown curve gets steadily flatter, reflecting a continuum of transmissivities corresponding to the effective depth of the cone of depression at any given time.

When pumping or recovery first begins, the vertical extent of the cone of depression is limited to approximately the well screen length. For most R-well pumping tests, these first few moments of pumping are the only time that the effective height of the cone of depression is known with certainty. Thus, the early data potentially offer the best opportunity to obtain hydraulic conductivity information, because conductivity would equal the earliest-time transmissivity divided by the well screen length.

Unfortunately, in the R-wells, casing storage effects dominate the early-time data, hindering the effort to determine the transmissivity of the screened interval. The duration of casing storage effects can be estimated using the following equation (Schafer 1978):

$$t_c = \frac{0.6\left(D^2 - d^2\right)}{\frac{Q}{s}},$$

where

t_c = duration of casing storage effect, in minutes
D = inside diameter of well casing, in inches (4.5 inches)
d = outside diameter of column pipe, in inches (2.375 inches)
Q = discharge rate, in gpm
s = drawdown observed in pumped well at time t_c, in feet

In some instances, it may be possible to eliminate casing storage effects by setting an inflatable packer above the tested screen interval prior to conducting the test. Therefore, this option has been implemented for the R-well testing program, including the R-34 pumping test. As will be explained later, using the packer was not completely successful in eliminating casing-storage-like symptoms, because of entrained air in the formation.

5.0 TIME-DRAWDOWN METHODS

Time-drawdown data can be analyzed using a variety of methods. Among them is the Cooper-Jacob method (1946), a simplification of the Theis equation (1935) that is mathematically equivalent to the Theis equation for pumped well data. The Cooper-Jacob equation describes drawdown around a pumping well as follows:

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S},$$

where

s = drawdown, in feet
Q = discharge rate, in gpm
T = transmissivity, in gpd/ft
t = pumping time, in days
r = distance from center of pumpage, in feet
S = storage coefficient (dimensionless)

The Cooper-Jacob equation is a simplified approximation of the Theis equation and is valid whenever the u value is less than about 0.05, where u is defined as follows:

$$u = \frac{1.87r^2 S}{Tt}.$$

For small radius values (e.g., corresponding to borehole radii), u is less than 0.05 at very early pumping times and, therefore, is less than 0.05 for all measured drawdown values. Thus, for the pumped well, the Cooper-Jacob equation can be considered a valid approximation of the Theis equation.

According to the Cooper-Jacob method, the time-drawdown data are plotted on a semilog graph, with time plotted on the logarithmic scale. Then, a straight line of best fit is constructed through the data points and transmissivity is calculated using:

$$T = \frac{264Q}{\Delta s},$$

where

T = transmissivity, in gallons per day (gpd)/ft
Q = discharge rate, in gallons per minute (gpm)
Δs = change in head over one log cycle of the graph, in feet

Because the R-wells are severely partially penetrating, an alternate solution considered for determining aquifer parameters is the Hantush equation for partially penetrating wells (1961a, b). The Hantush equation is as follows:

$$s = \frac{Q}{4\pi T}\left(W(u) + \frac{2b^2}{\pi^2 (l-d)(l'-d')} \sum_{n=1}^{\infty} \frac{1}{n^2}\left[\sin\frac{n\pi l}{b} - \sin\frac{n\pi d}{b}\right]\left[\sin\frac{n\pi l'}{b} - \sin\frac{n\pi d'}{b}\right] W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right),$$

where, in consistent units, s, Q, T, t, r, S, and u are as previously defined and

b = aquifer thickness
d = distance from top of aquifer to top of well screen in pumped well
l = distance from top of aquifer to bottom of well screen in pumped well
d' = distance from top of aquifer to top of well screen in observation well
l' = distance from top of aquifer to bottom of well screen in observation well
K_z = vertical hydraulic conductivity
K_r = horizontal hydraulic conductivity

In this equation, W(u) is the Theis well function, and W(u,β) is the Hantush well function for leaky aquifers. For single-well tests, d = d' and l = l'.

6.0 RECOVERY METHODS

Recovery data were analyzed by multiple methods. One of the methods used was the Theis Recovery Method. This is a semi-log analysis method similar to the Cooper-Jacob procedure.

In this method, residual drawdown is plotted on a semi-log graph versus the ratio t/t', where t is the time since pumping began, and t' is the time since pumping stopped. A straight line of best fit is constructed through the data points, and T is calculated from the slope of the line as follows:

$$T = \frac{264Q}{\Delta s}.$$

The recovery data are particularly useful compared to time-drawdown data. Because the pump is not running, spurious data responses associated with dynamic discharge rate fluctuations are eliminated. The result is that the data set is generally "smoother" and easier to analyze.

Recovery data also were analyzed using the Hantush method described above. In applying this procedure, simple recovery (difference between residual drawdown and maximum drawdown observed at the end of the pumping period) was plotted versus recovery time (t'). Such a plot can be considered analogous to a time-drawdown plot and is accurate for early and middle data. For late data, this approach can lose accuracy.

7.0 SPECIFIC CAPACITY METHOD

The specific capacity of the pumped well can be used to obtain a lower-bound value of hydraulic conductivity. The hydraulic conductivity is computed using formulas that are based on the assumption that the pumped well is 100-percent efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100-percent efficient, it follows that the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is unknown, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than or equal to the computed value.

For fully penetrating wells, the Cooper-Jacob equation can be iterated to solve for the lower-bound hydraulic conductivity. However, the Cooper-Jacob equation (assuming full penetration) ignores the contribution to well yield from permeable sediments above and below the screened interval. To account for this contribution, it is necessary to use a computation algorithm that includes the effects of partial penetration. One such approach was introduced by Brons & Marting (1961) and augmented by Bradbury & Rothchild (1985).

Brons and Marting introduced a dimensionless drawdown correction factor, sP, approximated by Bradbury and Rothschild as follows:

$$s_P = \frac{1-\frac{L}{b}}{\frac{L}{b}}\left[\ln\frac{b}{r_w} - 2.948 + 7.363\frac{L}{b} - 11.447\left(\frac{L}{b}\right)^2 + 4.675\left(\frac{L}{b}\right)^3\right].$$

In this equation, L is the well screen length, in feet. Incorporating the dimensionless drawdown parameter, the conductivity is obtained by iterating the following formula:

$$K = \frac{264Q}{sb}\left(\log\frac{0.3Tt}{r_w^2 S} + \frac{2s_P}{\ln 10}\right).$$

To apply this formula, a storage coefficient value must be assigned. Storage coefficient values for unconfined sand and gravel aquifers, such as the Puye Formation in which many of the R-wells are completed, typically range from a few percent to 20 percent or more, with the majority of the values falling between approximately 5 and 15 percent. Thus, in the absence of site-specific storage coefficient data for the Puye, a value of 0.1 is deemed to be a reasonable choice for performing the calculations for unconfined conditions. When confined conditions are encountered, the storage coefficient can be expected to range from about 10-5 to 10-3, depending on aquifer thickness (the thicker the aquifer, the greater the storage coefficient). Typically, a value of 5 x 10-4 may be assigned for calculation purposes. The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient is adequate to support the calculations. Because the water table in R-34 lies within the Puye Formation, unconfined conditions were assumed and a storage coefficient value of 0.1 was applied.

The analysis also requires assigning a value for the saturated aquifer thickness, b, which is generally not known. Fortunately, the calculated value of hydraulic conductivity is usually insensitive to the selected aquifer thickness value, as long as the aquifer thickness is significantly greater than the screen length. This is because saturated aquifer materials far above or below the screened interval contribute little to the yield of the well. Thus, it was expected that an approximate aquifer thickness estimate would suffice for the calculations. The known minimum saturated thickness of 272.5 feet was used in the calculations.

An alternative specific capacity method for partially penetrating screens is a formula presented by Hvorslev (1951) that can be derived directly from Darcy's Law:

$$K = \frac{229}{L}\frac{Q}{s}\ln\left(\frac{L}{2r_w} + \sqrt{1 + \frac{L^2}{4r_w^2}}\right),$$

where

K = hydraulic conductivity, in gpd/ft^2
Q = discharge rate, in gpm
L = well screen length, in feet
s = drawdown, in feet
r_w = borehole radius, in feet

This formula is derived based on the assumption of infinite aquifer thickness, above and below the well screen, and infinite pumping time. As such, it works reasonably well for short well screens completed in thick aquifers and very long pumping times. As with other specific capacity methods, the resulting K value may be considered to be a lower-bound estimate of the screened zone hydraulic conductivity.

Computing the lower-bound estimate of hydraulic conductivity can provide a useful frame of reference for evaluating the other pumping test calculations.

8.0 DATA ANALYSIS

This section presents the data obtained from the R-34 pumping tests and the results of the analytical analyses.

8.1 Initial Pumping Trials

The specific capacity observed during the first pumping trial was used to determine a lower bound estimate of aquifer hydraulic conductivity. Both the Hvorslev method and the Brons and Marting method were used for this.

During Trial 1, the well produced 17.8 gpm with 25.53 feet of drawdown after 48.37 minutes of pumping, for a specific capacity of 0.70 gpm/ft. Other relevant input parameters included a screen length (L) of 22.9 feet, an aquifer thickness (b) of 272.5 feet, a storage coefficient (S) of 0.1, and a borehole radius (rw) of 0.51 feet. The Hvorslev calculation produced a lower bound hydraulic conductivity value of 3.55 feet per day while the Brons and Marting procedure yielded 3.62 feet per day.

8.2 Background Data

Figure 2 shows the "apparent" water level hydrograph and the barometric pressure data recorded from 7:00 a.m. on September 12 to 7:00 a.m. on September 13. The barometric pressure fluctuated over a range of about 0.2 feet while the apparent hydrograph changed over a much narrower range. The water level data were recorded using a non-vented pressure transducer. The muted response range of the apparent hydrograph means that changes in the actual water levels in the well were nearly as great as the barometric pressure changes, and of opposite sign, so that the sum of the two (the apparent hydrograph) changed very little. This implied a high barometric efficiency and, because a non-vented transducer was used to record the data, no need to correct the water level measurements for barometric effects.

8.3 24-Hour Constant-Rate Pumping Test

The constant-rate pumping test was started at 6:04 a.m. on September 15 and continued until 6:04 a.m. on September 16. Recovery data were recorded for an additional 24 hours until the morning of September 17.

The discharge rate was monitored regularly throughout the pumping test. Figure 3 shows a plot of measured pumping rates versus time. As is evident from the graph, the pumping rate fluctuated significantly during the test. In most previous R-well pumping tests, the discharge rate has remained fairly steady throughout. The lack of a steady rate in the R-34 pumping test was probably caused by formation air running through the pump.

8.4 Drawdown

Figure 4 shows a semilog plot of the time-drawdown data. The early data showed a significant casing storage effect. The calculated casing storage duration was 27 minutes, meaning that data recorded prior to 27 minutes could not be analyzed.

The data after 27 minutes showed erratic response, probably because of discharge rate fluctuations. Some of the noise in the data set also might have been attributable to dynamic hydraulic conductivity changes induced by ongoing degassing of the formation water. Changing gas content in the formation pores can change hydraulic conductivity significantly. Because of the poor data set, time-drawdown analyses were not performed.

8.5 Recovery

Figure 5 shows a semilog recovery plot of residual drawdown versus t/t'. Surprisingly, the data trace showed a casing-storage-like response, even though the down-hole packer had been inflated prior to pump shut off.

This perplexing result could very well have been caused by compression of entrained air during the recovery. As the head built up, entrained air bubbles or air pockets would compress in response to the increasing applied head. This would have the effect of the aquifer system "absorbing" water volume, much the same way that an empty well casing absorbs water volume during a recovery test conducted without an inflatable packer – a "bubble" storage effect instead of a casing storage effect. This result was disappointing because it meant that the otherwise valuable early recovery data could not be used in the hydraulic analyses.

Figure 6 shows an expanded scale plot of the recovery data. It appears that the storage effect persisted for about 7 minutes; that is, until a t/t' value of about 200. The subsequent data trace showed two slopes – the first slope yielding a calculated transmissivity of 5070 gpd/ft, gradually transitioning to a flatter slope yielding a calculated transmissivity of 12,300 gpd/ft.

It is likely that continued vertical expansion of the recovery "cone of impression" caused the steady flattening of the recovery curve. It is also possible that aquifer heterogeneity is reflected in the slope changes as well. If it could be assumed that the transmissivity of 12,300 gpd/ft was associated with the drilled aquifer thickness of 272.5 feet, the corresponding hydraulic conductivity value would be 6.0 feet per day. However, it is also possible that the transmissivity of 12,300 gpd/ft corresponded to a greater or lesser sediment thickness, which would make the computed hydraulic conductivity less than or greater than 6.0 feet per day, respectively. Using this analysis technique, it is not possible to determine the hydraulic conductivity precisely, because the vertical height of the cone of impression at any given time is not known.

Note that the late recovery data showed a rapid increase in water level; i.e., groundwater mounding above the static water level. The sudden rise in water level occurred more than 20 hours after pump shutoff. There was no explanation for the timing of this unusual response. Other observed mounding events during recovery left unanswered questions about the response as well. For example, notice on Figure 1, introduced previously, that the two major mounding events ended suddenly, rather than transitioning gradually (asymptotically) back to the static water level.

Because of the baffling pressure responses observed in this regard, the possibility was considered that the pressure transducer might have malfunctioned because of the presence of the gas phase. However, the equipment manufacturer asserted that the transducer could be expected to function properly whether exposed to air or water or both. Thus, it was assumed that the data, as recorded, provided a valid representation of down-hole pressure conditions.

To account for the effects of partial penetration in the recovery data set, the Hantush method was applied to quantify the formation properties. Figures 7, 8, and 9 show curve matching results for assumed vertical anisotropy ratios of 1.0, 0.1 and 0.01, respectively. As shown on the graphs, the resulting hydraulic conductivity values ranged from 3.1 feet per day to 3.9 feet per day, depending on vertical anisotropy.

Figure 10 shows a side-by-side comparison of the drawdown and recovery data so that the storage effects can be compared. Although the storage effect during recovery was significantly attenuated (a few minutes duration versus 27 minutes for the time-drawdown data), the effect was still prominent and produced a curve that was quite similar to the time-drawdown casing storage response.

Figure 11 shows early recovery data from the brief trial tests that were introduced earlier on Figure 1. These recovery plots show the same apparent storage type effect as the recovery response that followed the constant-rate pumping test. This confirms the occurrence of air formation early on, during the initial stages of pumping.

8.6 Specific Capacity Analysis

Well R-34 produced 19.4 gpm with a drawdown of 73 feet during the 24-hour constant-rate pumping test, making the specific capacity 0.27 gpm/ft. This was substantially less than the specific capacity of 0.70 gpm/ft observed during the first trial pumping event.

The most likely explanation for the reduced specific capacity is that entrained air in the formation pores near the screen reduced the hydraulic conductivity. It is well known that partial saturation reduces sediment hydraulic conductivity significantly. Trapped air in the formation pores blocks the flow of water, thereby reducing the overall ease with which water moves through the sediments.

Applying the Hvorslev method and Brons and Marting method to the pumping rate and drawdown observed during the constant-rate test yielded hydraulic conductivity values of 1.35 feet per day and 1.42 feet per day, respectively. However, these values were not useful because they were apparently biased by air buildup in the aquifer and were substantially less than previously obtained lower-bound values for hydraulic conductivity.

9.0 SUMMARY

The following information was determined from the pumping and recovery tests on R-34:

1. The barometric efficiency of R-34 was high, consistent with observations from all of the R-well pumping tests. It was not necessary to correct the pumping test data for barometric pressure effects.
2. The large quantities of air previously injected into the aquifer during drilling apparently had saturated the groundwater with air to a sufficient extent that the pressure reduction caused by pumping the well induced air to come out of solution.
3. Release of air in the formation pores caused groundwater mounding following each pumping event, having an effect similar to injecting air or water into the aquifer.
4. The presence of air in the formation water interfered with pump operation, resulting in either erratic discharge rate fluctuations or no flow at all.
5. Buildup of air in the formation pores reduced the hydraulic conductivity of the sediments around the well, causing a reduction in the specific capacity of the well, from 0.70 gpm/ft initially, to 0.27 gpm/ft during the 24-hour pumping test.
6. Implementation of the inflatable packer successfully eliminated casing storage effects. However, the recovery data showed a similar effect, likely caused by compression of the air entrained in the casing and formation pores, and thus, it was not possible to obtain valid early recovery data.
7. The specific capacity data suggested a lower bound hydraulic conductivity for the sediments in the vicinity of the screen of about 3.6 feet per day.
8. The semi log analysis of the recovery data yielded a hydraulic conductivity value of roughly 6.0 feet per day (plus or minus, depending on what the corresponding effective vertical height of the cone of impression was).

9. Hantush analysis of the recovery data yielded an estimated hydraulic conductivity range of 3.1 feet per day to 3.9 feet per day, depending on the magnitude of assumed vertical anisotropy ratio. This range is considered consistent (not in conflict) with the lower bound value of 3.6 feet per day obtained from the specific capacity data.

10. The apparent phenomenon of entrained air in the formation was perplexing and unexpected. It resulted in an extra pump removal and installation to diagnose the problem. Also, it added significant complexity to the data interpretation and caused the very early time data to be unusable.

10.0 REFERENCES

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Figure 1. Initial Trial Tests

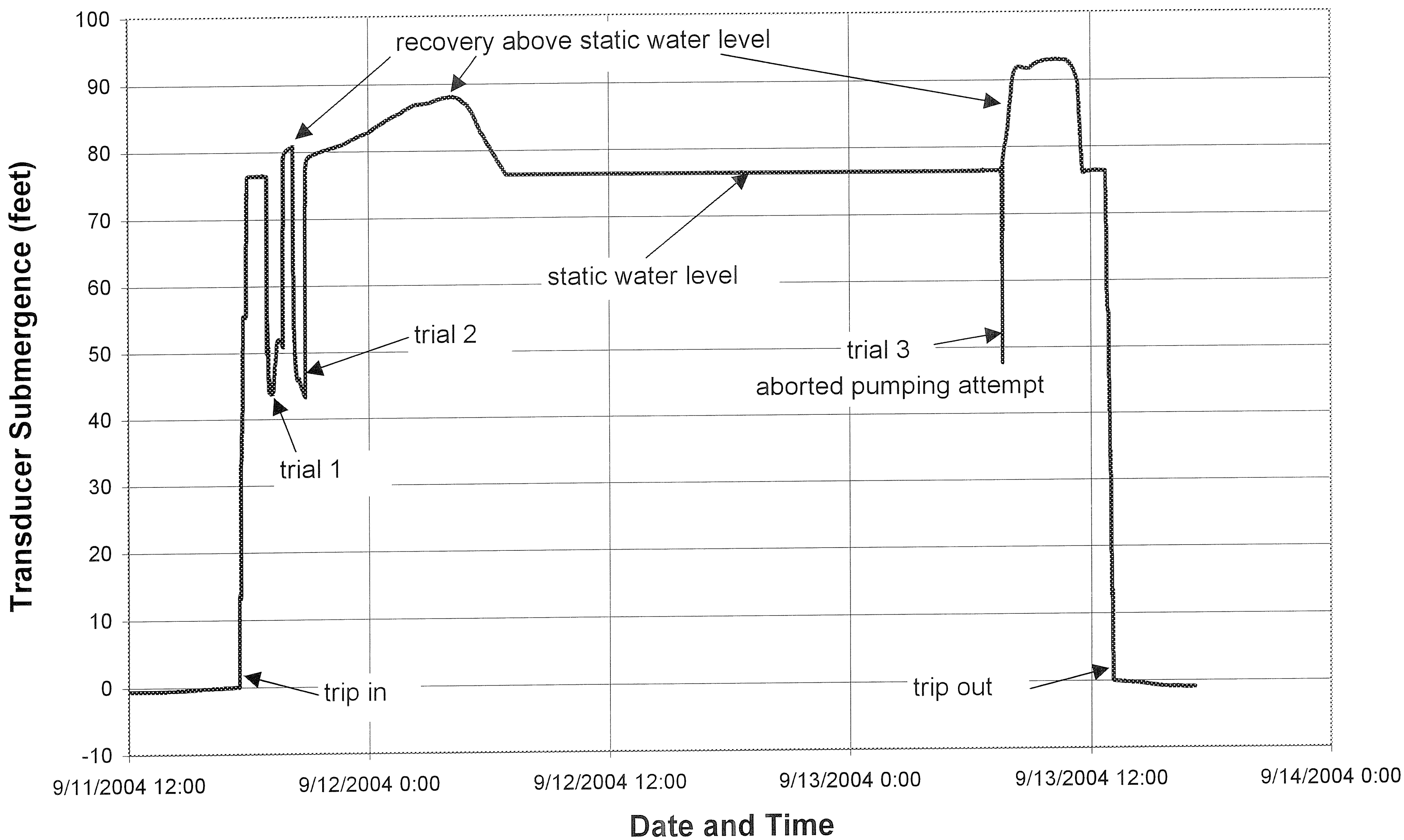


Figure 2. Comparison of R-34 Apparent Hydrograph (10-Minute Rolling Average) and TA-54 Adjusted Barometric Pressure

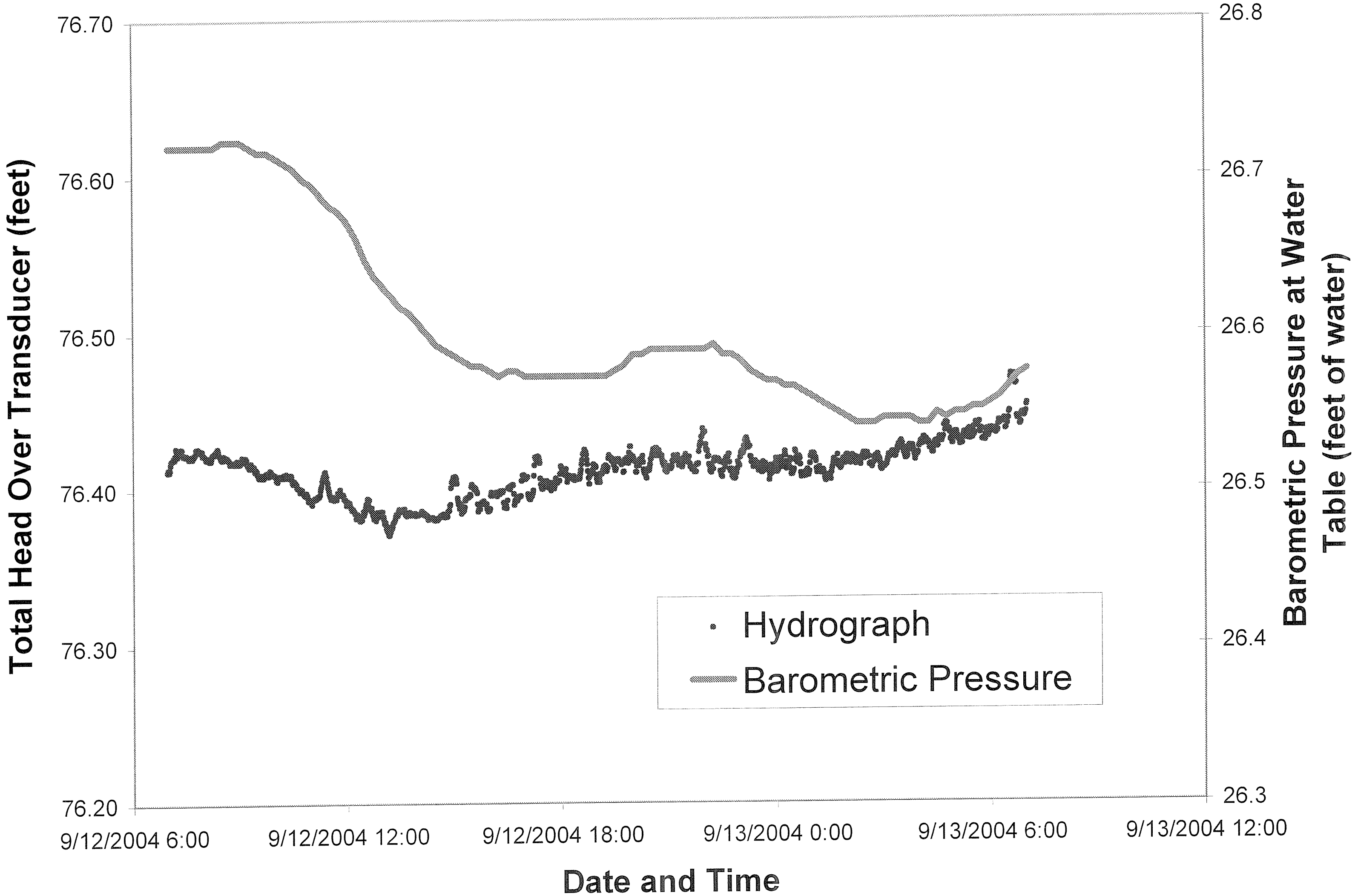


Figure 3. Pumping Rates

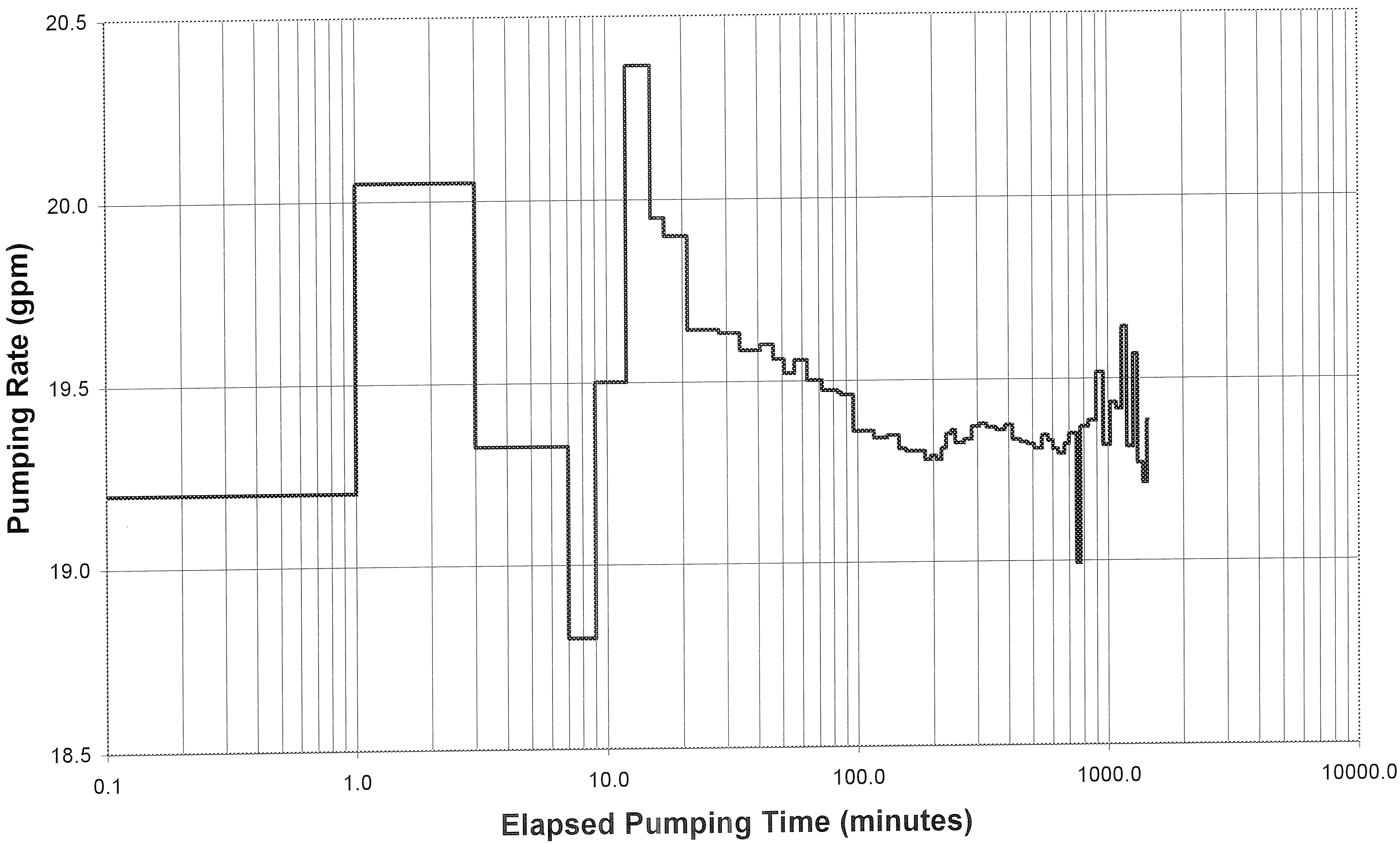


Figure 4. Well R-34 Drawdown

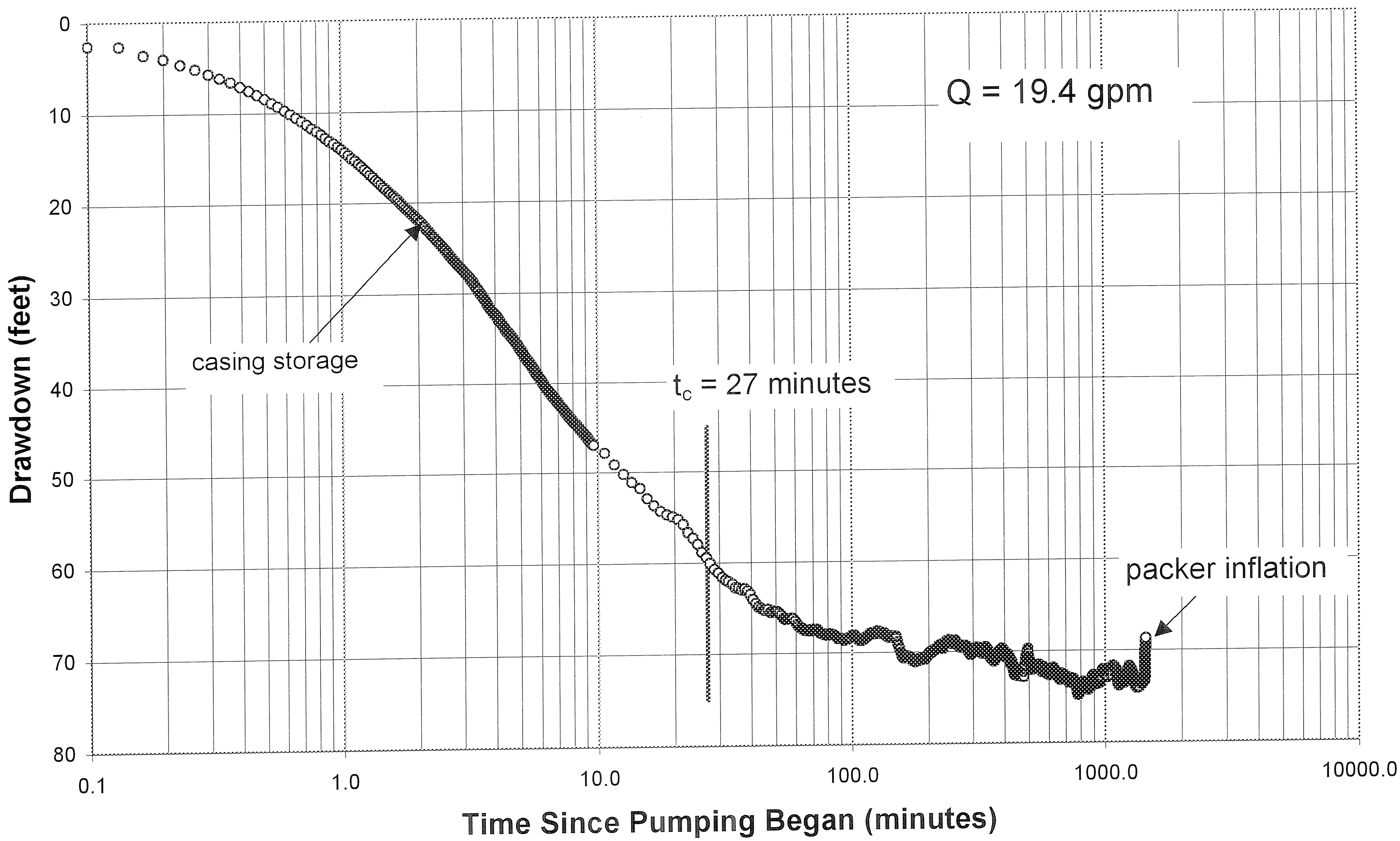


Figure 5. Well R-34 Recovery

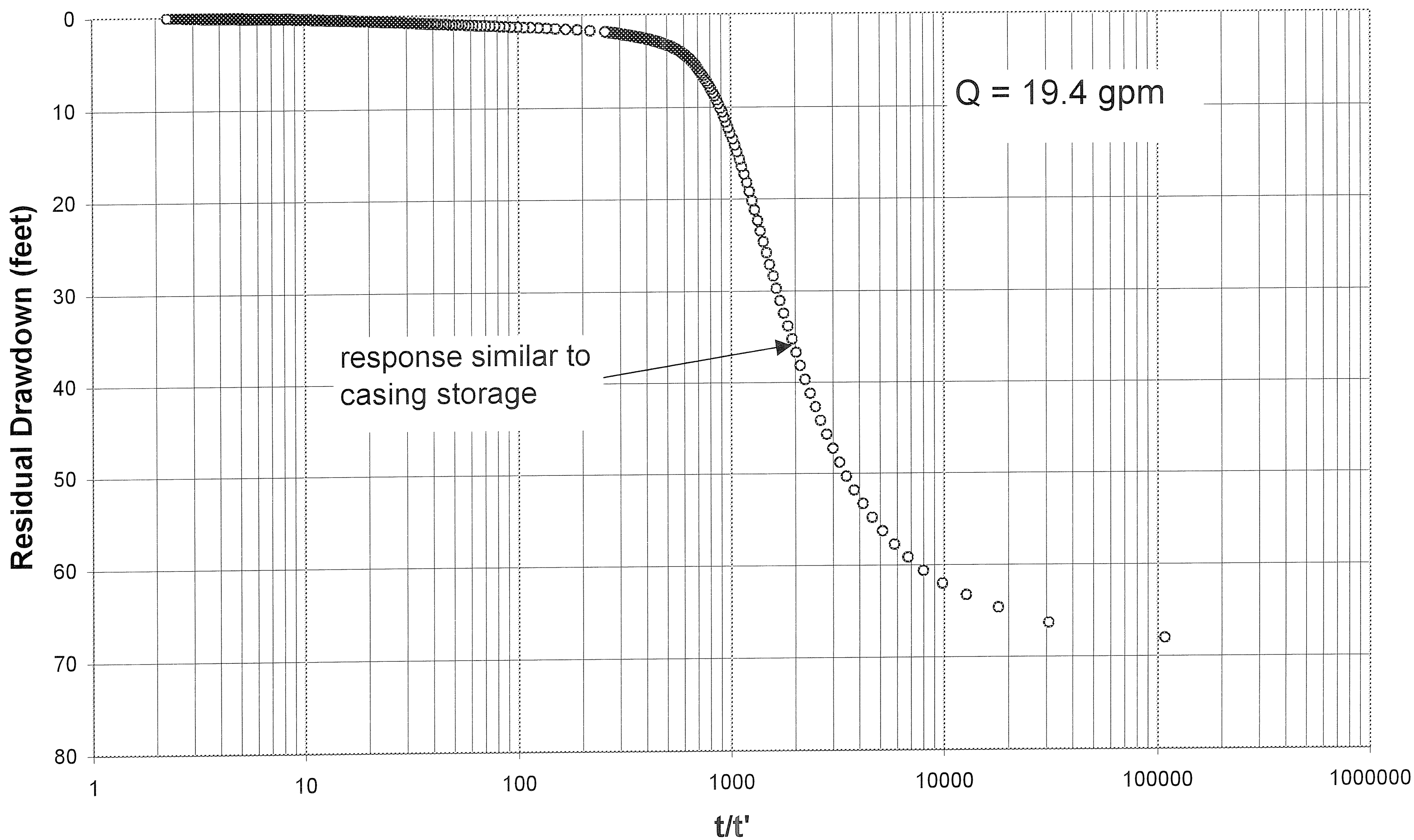


Figure 6. Well R-34 Recovery - Expanded Scale

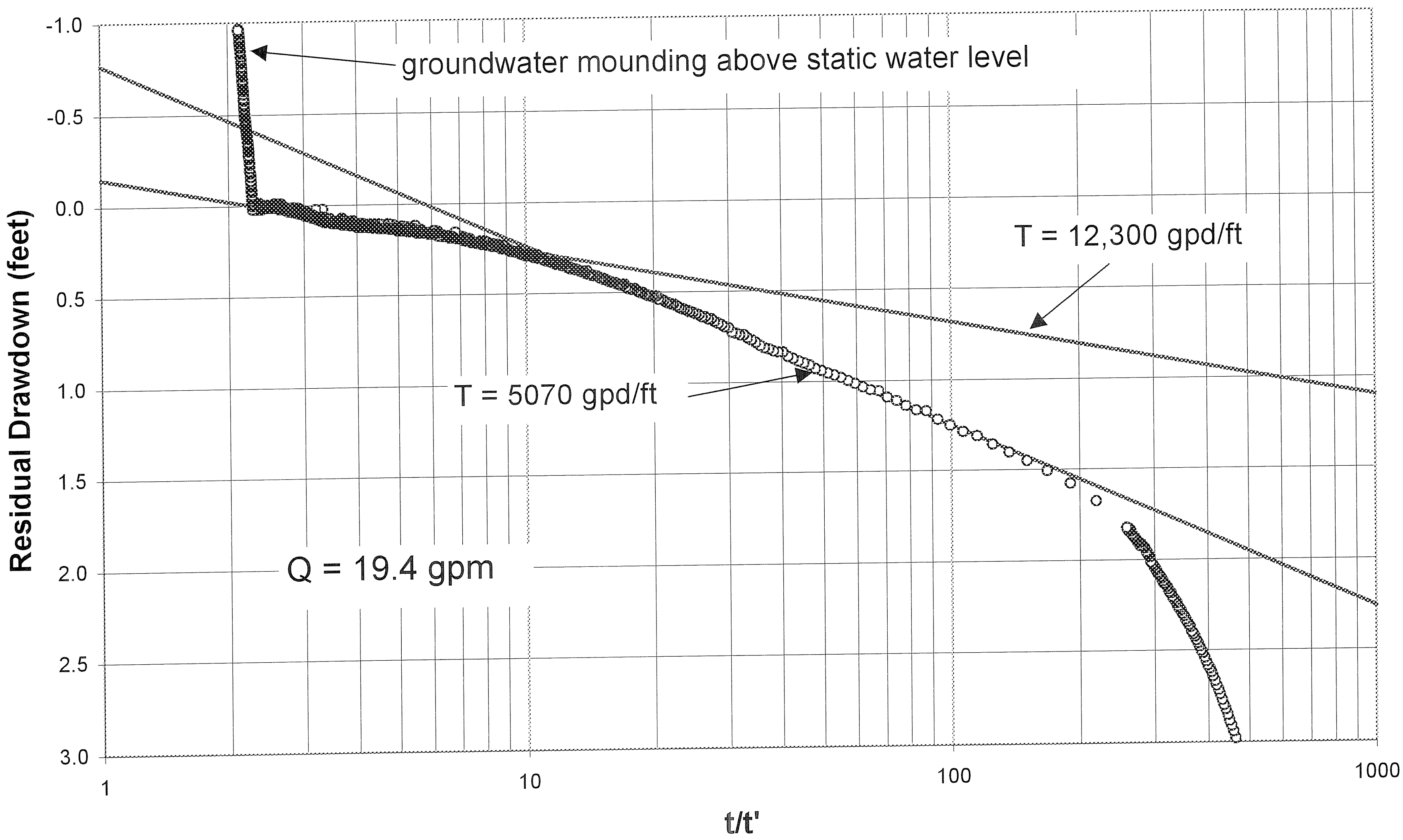


Figure 7. Well R-34 Recovery
Hantush Solution For Anisotropy of 1.0

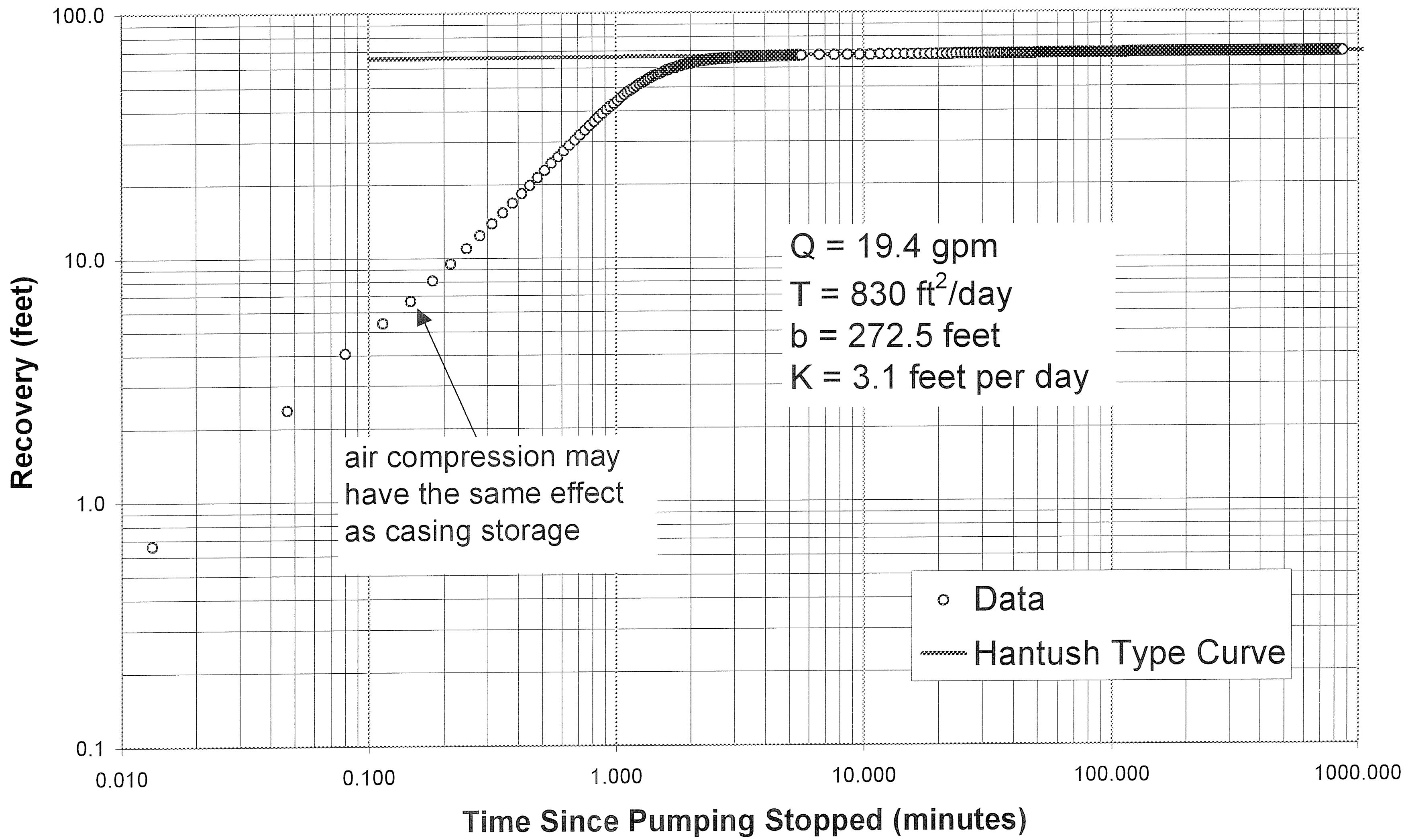


Figure 8. Well R-34 Recovery
Hantush Solution For Anisotropy of 0.1

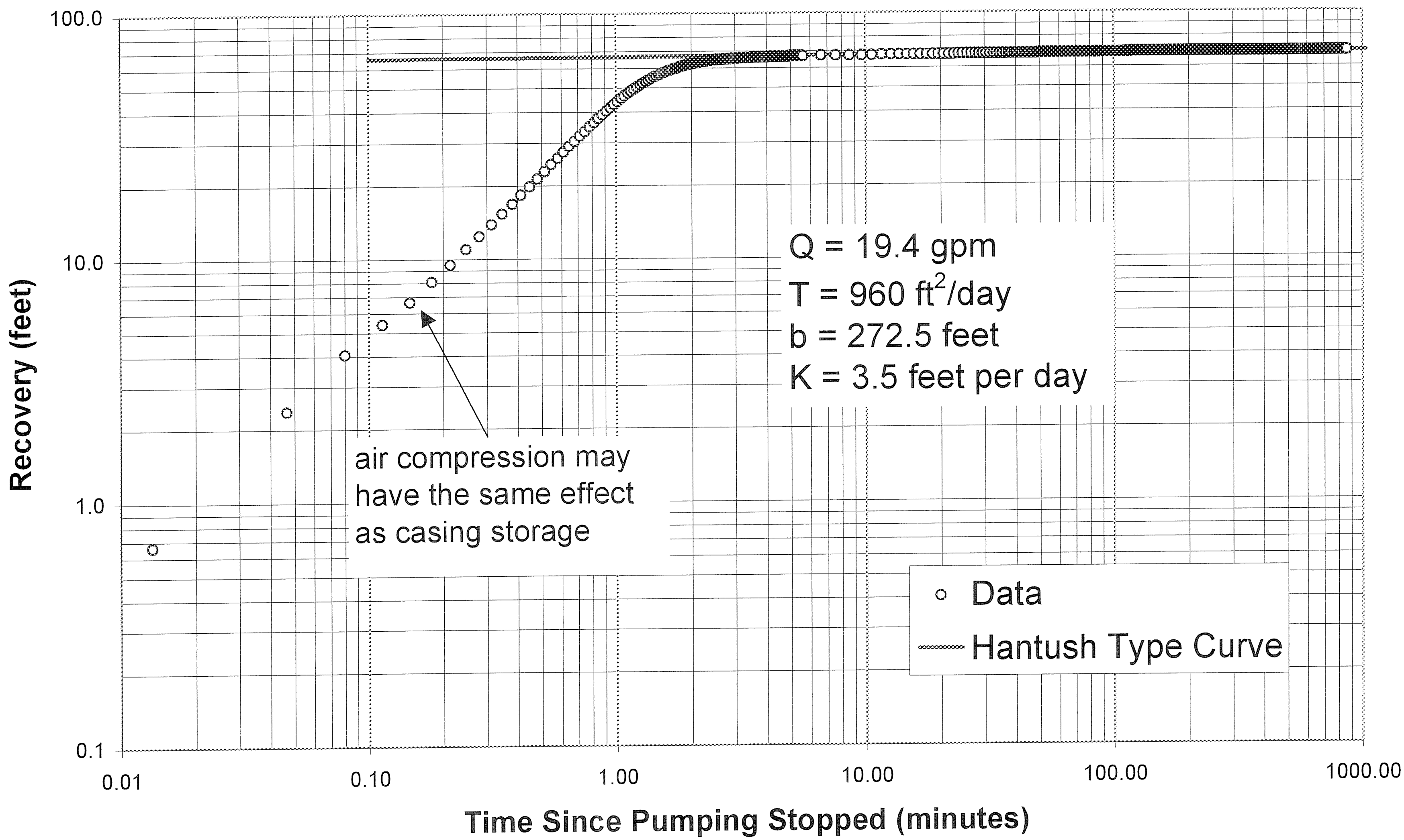


Figure 9. Well R-34 Recovery
Hantush Solution For Anisotropy of 0.01

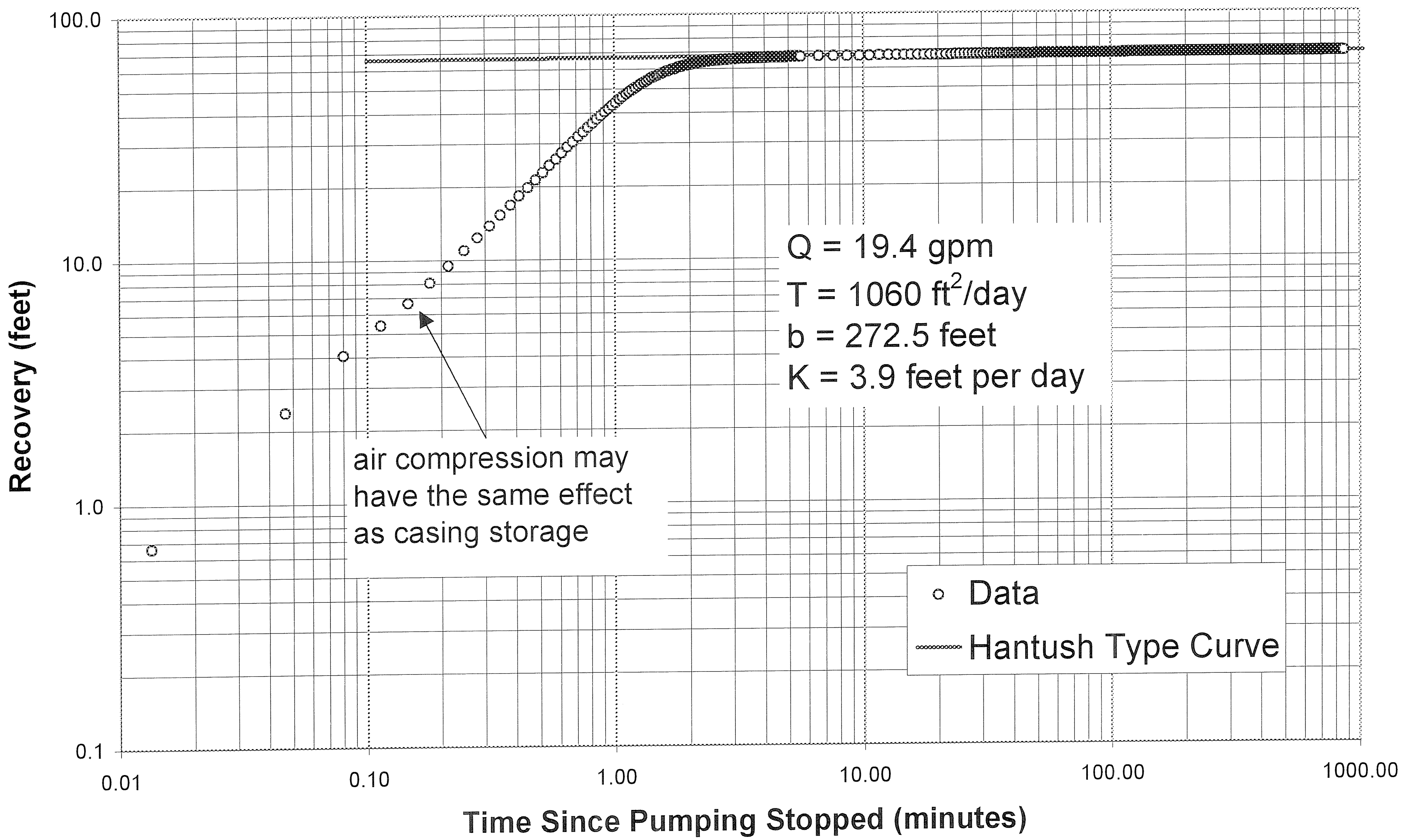


Figure 10. Well R-34 Drawdown and Recovery Comparison

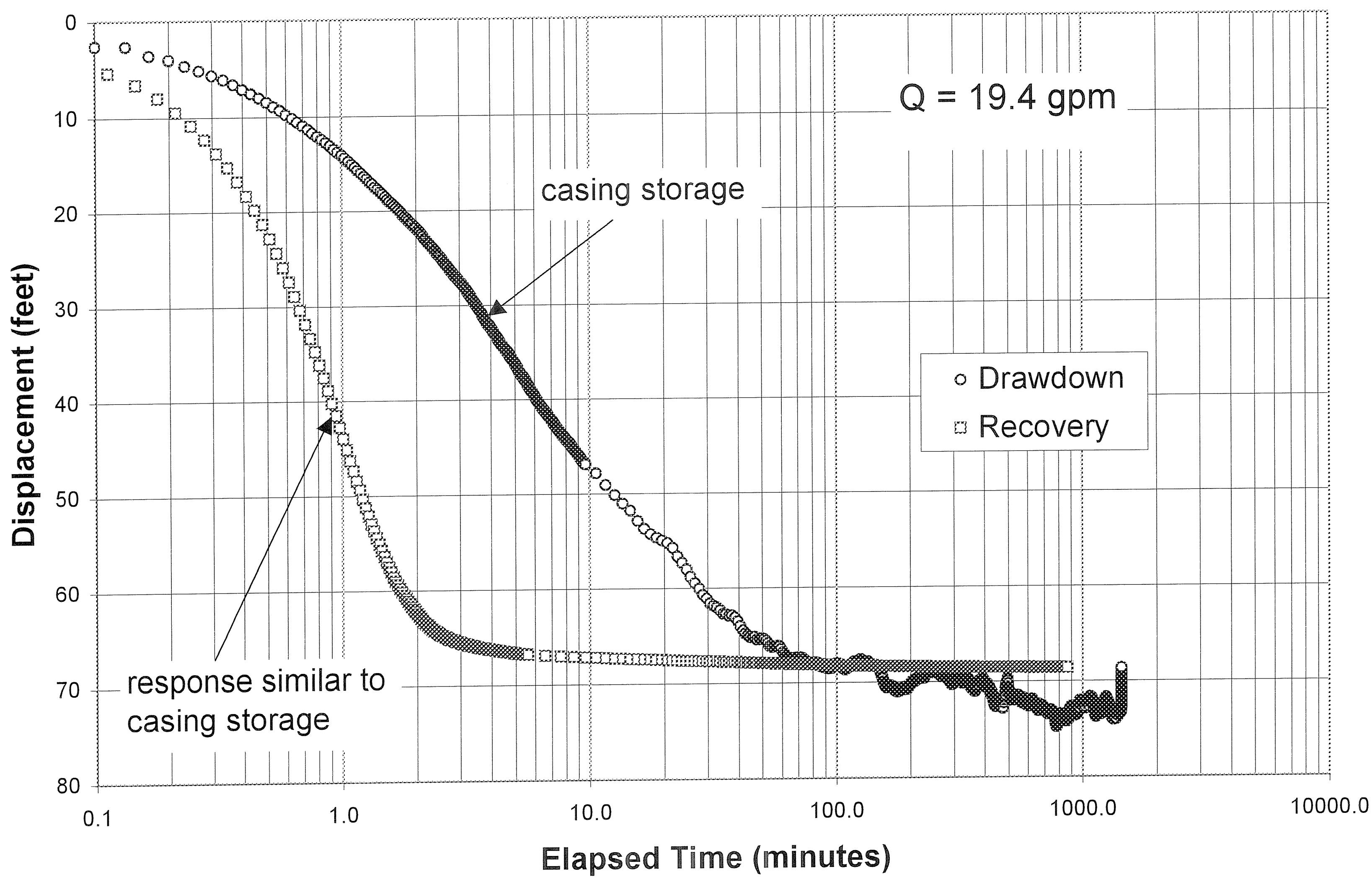
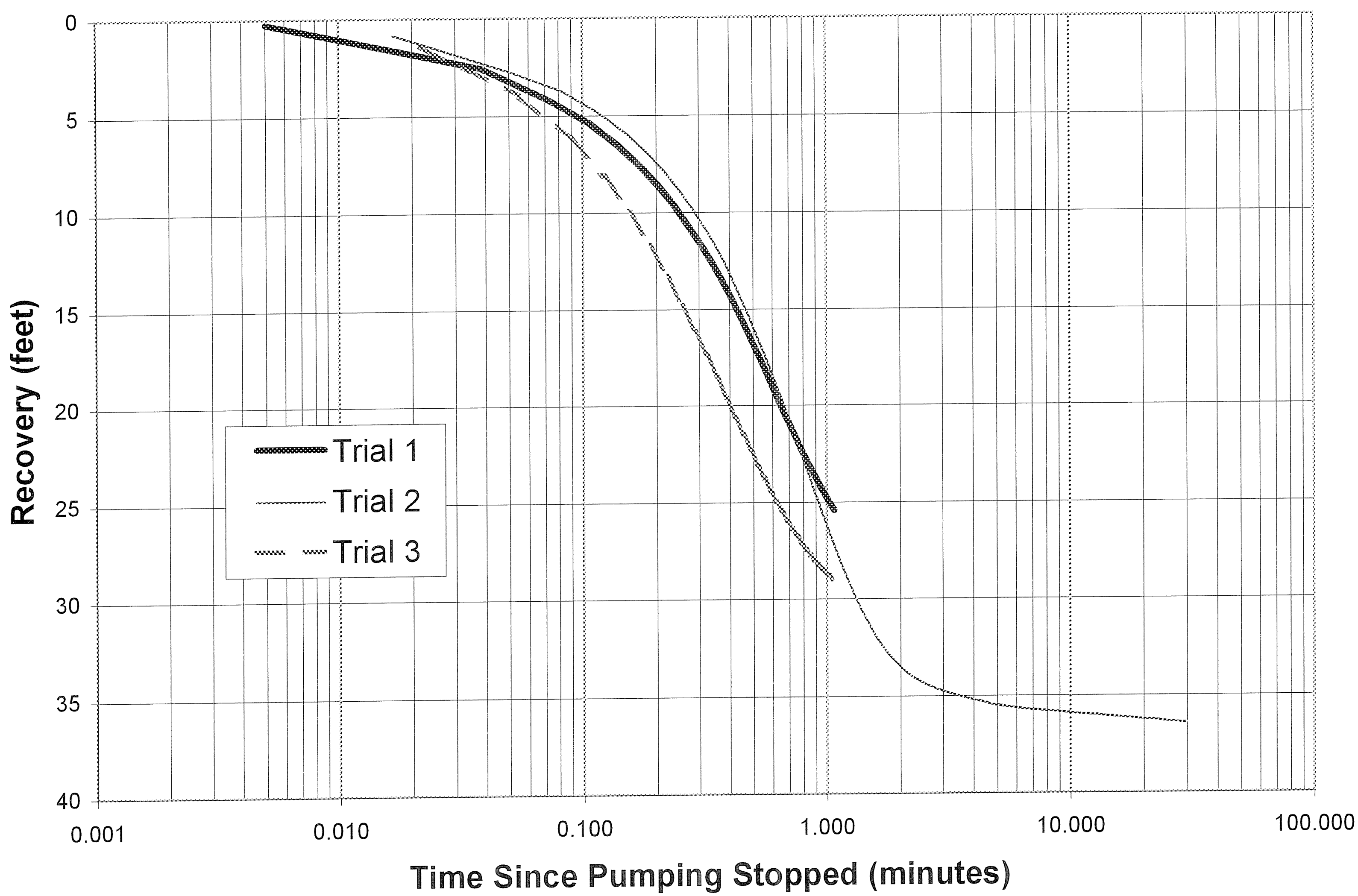


Figure 11. Well R-34 Recovery During Trial Tests



Appendix F

NMED Discharge Approval and
Discharge Media Analytical Results

-----Original Message-----
From: Chris Vick [mailto:chris_vick@nmenv.state.nm.us]
Sent: Wednesday, November 10, 2004 3:16 PM
To: Bob Beers
Cc: Karen Menetrey; John Young; Whitacre, Thomas; Enz, Robert D.
Subject: Land Application of Drilling and Development Water for R-33 and R-34

Bob-

This email confirms NMED approval for the discharge of drilling and development water from Workplan Wells R-33 and R-34. The drilling and development water must be discharged as described in the Hydrogeologic Workplan NOI dated August 7, 2002. The discharge of this water must also be in accordance with the NOI ammendment dated November 4, 2004.

If you have any questions and/or concerns please feel free to contact me.

Sincerely,

Chris

Christopher F. Vick
Environmental Scientist and Specialist
Groundwater Pollution Prevention Section
New Mexico Department of Environment
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Fax (505) 827-2965

Discharge Media Analytical Results are located on the CD on the back cover of this report.

Appendix G

Deviations From Planned Activities

Deviations from Planned Activities

Activity	Hydrogeologic Workplan[a]	Sampling and Analysis Plan[b]	Actual Work
Total Borehole Depth	1,100 feet (ft) below ground surface (bgs). Penetrate to a depth of 100 ft below the regional water table.	1,015 ft bgs, approximately 100 ft below the anticipated regional water table.	1,065 ft bgs, approximately 269 ft into the regional aquifer. Static water level in the regional aquifer measured in the well at 796 ft bgs.
Drilling Method	Methods may include, but are not limited to hollow-stem auger (HAS), air-rotary/Odex/Stratex, air-rotary/Barber rig, direct push, and hand auger methods.	Method specified as fluid-assisted, open-hole, air -rotary drilling.	R-34 drilled using fluid-assisted, open-hole, air-rotary methods; drill bits used included milltooth tricone bit, button bit with down-the-hole hammer, and button tooth bit.
Water Samples Collected for Contaminant Analysis	Water samples to be collected if perched water encountered during drilling. Collect screening water samples during drilling at the top of the regional aquifer. Install well screen to collect water quality data for regional aquifer.	Water samples to be collected if perched water encountered during drilling. Collect screening water samples during drilling at the top of the regional aquifer. Install well screen to collect water quality data for regional aquifer.	Two water samples collected from the borehole, one during drilling and one following well construction.
Water Sample Analysis	Initial sampling: radiochemistry I, II, and III analytes, tritium (^{3}H), general inorganics, stable isotopes, volatile organic compounds (VOCs), and metals. Saturated zones: radionuclides (tritium, strontium-90, cesium-137, americium-241, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross-alpha, gross-beta, and gross-gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements.	Metals (total and dissolved), anions (bromide, chlorate, chloride, fluoride, nitrate, nitrite, perchlorate, orthophosphate, sulfate), dissolved silica, total cyanide, tritium, tritium (low level), americium-241, plutonium-238, -239 and -240, strontium-90, technetium-99, uranium-234, -235, -236, and –238, gamma spectroscopy, gross-alpha, gross-beta, and gross-gamma.	Results presented in Appendix A
Number of Core/ Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification per borehole.	Contaminant analysis will be performed on cuttings collected at regular intervals. A total of 29 target depths are estimated for cuttings samples.	No cuttings samples submitted for contaminant analysis due to lost circulation problems preventing sample collection
Core/Cuttings Sample Analysis	Uppermost sample to be analyzed for a full range of compounds. Deeper samples to be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low and high detection levels), and metals. Four samples to be analyzed for VOCs.	Anions, cations, and stable isotopes (bromide, bhloride, fluoride, iodide, nitrate, nitrite, oxalate, phosphate, sulfate, carbonate alkalinity, perchlorate, arsenic, strontium, uranium, aluminum, calcium, iron, magnesium, manganese, sodium, and potassium, $^{18}O/^{16}O$, $^2H/^1H$, nitrogen isotopes) and radionuclides (tritium, americium-241, plutonium-238, plutonium-239 and -240, strontium-90, technetium-99, uranium-234, uranium-235, uranium-238, gamma spectroscopy).	None
Laboratory Hydraulic-Property Tests	Analysis of physical properties to be conducted on five core samples, including moisture	No samples specified for laboratory hydraulic analysis.	No samples collected for laboratory hydraulic analysis.

Activity	Hydrogeologic Workplan[a]	Sampling and Analysis Plan[b]	Actual Work
	content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.		
Geology	Ten samples of core or cuttings to be collected for petrographic, X-ray fluorescence, and X-ray diffraction analyses.	Geology task leader to determine number of samples for characterization of mineralogy, petrography, and geochemistry based on geologic and aquifer conditions encountered during drilling.	Geology based on geologic interpretation of cuttings samples collected during drilling and geophysical logs
Geophysics	In general, open-hole geophysics to include array induction tool, triple-detector litho-density, combinable magnetic resonance, gross gamma ray, natural gamma spectroscopy, epithermal compensated neutron, caliper, formation micro-image, and elemental capture spectroscopy; cased-hole geophysics to include triple-detector litho-density, gross gamma ray, natural gamma spectroscopy, epithermal compensated neutron, and elemental capture spectroscopy.	Typical wireline logging service as planned. Open-hole geophysics to include array induction imager, triple lithodensity, combinable magnetic resonance tool, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron log, caliper, full-bore formation micro-imager, elemental capture spectrometer and borehole video; cased-hole geophysics to include triple lithodensity, natural gamma, natural gamma spectrometry, epithermal compensated neutron log, and elemental capture spectrometer.	Schlumberger open-hole geophysical logging surveys conducted at R-34 included: compensated neutron tool: 923 ft bgs triple litho-density: 923 ft bgs array induction tool: 911 ft bgs elemental capture spectroscopy: 908 ft bgs natural gamma spectroscopy: 911 ft bgs combinable magnetic resonance: 908 ft bgs full-bore Fm micro-imager: 918 ft bgs Schlumberger cased-hole geophysical logging surveys conducted at R-34 included: compensated neutron tool: 740 ft bgs triple litho-density: 740 ft bgs LANL video logging performed in open hole in the interval 739 to 796 ft bgs.
Water-Level Measurements	Procedures and methods not specified in Hydrogeologic Workplan.	Water levels to be determined for each saturated zone by electric water-level meter or by pressure transducer.	Electric water level meter (sounder) used to measure zones of perched saturation (i.e., attempted measurements) and regional water table.
Field Hydraulic-Property Tests	Not specified in Hydrogeologic Workplan.	Slug or pumping tests may be conducted in saturated intervals once the well is completed.	Hydraulic pumping tests at R-34 conducted in September 2004.
Surface Casing	Approximately 20-inch outer diameter (OD) casing extending from land surface to 10-ft depth in underlying competent layer and grouted in place.	Not specified in SAP.	13⅜-inch OD steel casing installed to 59 ft bgs and subsequently removed during R-34 well construction.
Minimum Well Casing Size	6.625-inch OD.	Not specified in SAP.	5-inch OD (4.5-inch ID) stainless steel casing with external couplings.
Well Screen	Machine-slotted (0.01-inch) stainless-steel screens with flush-jointed threads; number and length	Not specified in SAP.	Single screen constructed of 5.0-inch OD, wire-wrapped, rod-based stainless steel, 0.020-inch slot

Activity	Hydrogeologic Workplan[(a)]	Sampling and Analysis Plan[(b)]	Actual Work
	of screens to be determined on a site-specific basis and proposed to New Mexico Environment Department.		size, with external couplings.
Backfill	Uncontaminated drill cuttings below sump and bentonite above sump.	Not specified in SAP.	Sloughing in the borehole occurred from 975-1,065 ft bgs and 667-717 ft bgs. Bentonite/sand backfill constructed below the screen in the interval 975-1,065 ft bgs.
Filter Material	>90% silica sand, properly sized for the 0.010-inch slot size of the well screen, extending 2 ft above and below the well screen.	Not specified in SAP.	Primary filter pack constructed of 8/20 silica sand placed 6.7 ft above and 28.4 ft below the screen, respectively; secondary filter pack constructed of 2 ft of 20/40 silica sand placed above primary filter pack.

(a) These activities are specified in the following document: LANL 1998, "Hydrogeologic Workplan," Los Alamos National Laboratory 1998-59599, May 22, 1998

(b) These activities are specified in the following document: LANL, 2003. "Sampling and Analysis Plan for Drilling and Testing Characterization Wells R-1, R-34, R-33, and R-34," Los Alamos National Laboratory Report LA-UR-03-8324, Los Alamos, New Mexico, September 2003.